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Peatland Hydrology, Bog 569 Pigeon Hill, New Brunswick

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New Nouveau
Brunswick

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Mineral Resources

Open File Report 91-10

Peatland Hydrology, Bog 569 Pigeon Hill, New Brunswick

GEMTEC Limited

A study carried out for the
New Brunswick Department
of Natural Resources and Energy,
Mineral Resources

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ATTN: MR. JACQUES THIBAULT

Dear Mr. Thibault:

RE: PEATLAND HYDROLOGY, BOG 569, PIGEON HILL, NEW BRUNSWICK

Please find enclosed 20 bound copies and one unbound original of our report on this project. All requested changes have been made with one exception. The reference to North Carolina (in terms of suspended solid concentrations) remains, but has been qualified.

Should you have any questions please contact the undersigned at your convenience.

Yours truly,

G. R. E. DICKINSON, P. ENG.

GRED/mr

Enclosures

EXECUTIVE SUMMARY

This study was solicited by the New Brunswick Department of Natural Resources to address some of the issues involved in peatland development. Draining of peatlands for peat production can result in degraded runoff water quality characterized by increased suspended solids, dissolved organic carbon and reduced pH. Without mitigation, these problems are perceived to have major environmental implications on downstream aquatic ecosystems.

The medium size (290 ha) peat bog selected for the study is located on the island of Lameque in north-eastern New Brunswick. A fifty hectare portion is currently operated by La Tourbe de Pigeon Hill Ltee., for horticultural purposes. The annual production is approximately 125,000 bales or, in loose form, 45,000 cubic metres. An estimated 2.2 million cubic metres of peat occurs above the level of the lake located within the bog (DNR, 1977).

The hydrologic characteristics of the bog were evaluated through field measurements of precipitation, groundwater levels, surface runoff, and surface water quality over a three-month period during the fall of 1990.

Precipitation was continuously measured using a tipping-bucket rain gauge installed in the village of Pigeon Hill. Groundwater levels were measured at 13 different piezometer locations throughout the bog. Surface runoff was measured at seven strategic locations, using V-notch weirs. Data were continuously recorded at two piezometers and three weirs, with supplementary manual readings for the remainder of the installations.

A total of 42 rainfall events occurred during the field program. These ranged in magnitude from 0.2 mm to 75 mm of rain. Surface runoff as measured over the period typically averaged 0.00025 - 0.00050 m^3/s per hectare with peak runoff values of 0.001 - 0.002 m^3/s per hectare during rainfall events.

Two groundwater systems were found at the site. The upper system is a perched water table located within the peat bog. An independent, confined groundwater system occurs within the bedrock below the bog. The potentiometric surface in the lower system was consistently 2 metres below the perched bog water level. The two systems are separated by a layer of relatively impervious glacial till soil.

Detailed analysis of the precipitation, runoff and groundwater data indicated that surface runoff is greatly influenced by the antecedent conditions in the peat as well as by the magnitude of precipitation. The variables most affecting runoff were the level of the water table within the bog and the rate of infiltration of water into the bog surface.

A simple model, derived from the Rational Method, was developed for estimation of the peak runoff, Q.

$$Q = CIA \quad \text{where} \quad C = C_1 \cdot C_2 \cdot C_3$$

where Q = runoff in m^3/s

I = rainfall intensity in m/s

C_1 = a factor relating to bog water level with a range of 0.05 for low water levels to 1.0 for a fully saturated bog.

C_2 = a factor relating to the ability of rainfall to infiltrate into the bog with a range of 0.5 for low intensity rains to 1.0 for very high intensity storms.

C_3 = a surface condition factor indicative of the slopes and level of development of the bog. A factor of 0.5 was selected for the Pigeon Hill study.

A = surface area in m^2

The runoff coefficient C was found to vary between 0.02 and 0.16. Corresponding ranges of C_1 and C_2 were 0.5 to 1.0 and 0.05 to 0.95, respectively. The maximum value of C for Pigeon Hill would be 0.5 for a fully saturated bog and high intensity rainfall.

Surface water samples were obtained weekly at the seven weir locations. These samples were analyzed for suspended solids and pH (acidity).

Suspended solids levels in the runoff varied from 0.5 to 104 mg/l and averaged 10.7 mg/l. A value of 20 mg/l is considered the maximum from the point of view of potential environmental impact in surface water discharge areas. The total dry weight of suspended solids in runoff from a 124.4 ha area was calculated at 820 kg over the period Oct. 7 - Nov. 27, 1990. The suspended solids concentrations did not vary directly with the surface flows or velocities but are probably influenced by ditch construction and maintenance, by operational practises, and by environmental factors such as wind.

Laboratory tests on samples of milled peat indicated that the settling characteristics of peat in water are influenced by the particle size, the degree of wetting and the specific gravity. Dry peat tends to float until thoroughly wetted. Wetting of larger particles occurs more slowly than small particles thus the smaller particles settle out first.

Acidity (pH) values in the surface runoff ranged from pH 4.20 to pH 6.24. In general, lower values in the 4.2 - 4.8 range were recorded nearest the developed areas. The higher values are believed to be influenced by the presence of mineral soils in some ditches. There was a trend to increasing pH values with time perhaps due to dilution effects of rainfall during the period.

Settling ponds for removal of suspended solids can be designed based on the data developed during this study. However, additional field studies of the performance of such facilities are required. For a drainage area of 50 ha, a pond of 70 m long by 5 m wide by 2 m deep with a clean-out interval of 6 months should prove adequate.

Features which will improve settling pond characteristics are: a mechanism at the influent end to induce turbulence and wetting of floating peat (such as a weir), and a skimmer at the outlet to retain floating peat.

As noted previously, some additional field work is required to optimize the design and performance of settling ponds. This should include further evaluation of the suspended solids discharge from operating bogs by periodic measurement of solids trapped, perhaps combined with measurement of solids levels in both influent and effluent flows. Additional laboratory tests are warranted to more fully evaluate the settling characteristics of peat. It would also be useful to obtain runoff measurements in other bogs to refine the hydrologic model developed herein and to evaluate its applicability to other bogs.

SOMMAIRE

L'étude fut motivée par le besoin d'obtenir des données précises quand au régime hydrologique des tourbières commerciales. En effet, puisque le drainage des tourbières commerciales entraîne une évacuation d'eau vers des systèmes aquatiques environnants, il est important de pouvoir estimer les débits d'eau et les charges probables de sédiments afin de construire, là où c'est nécessaire, des ouvrages d'interception aux dimensions appropriées qui serviront à minimiser l'impact des opérations de drainage sur l'environnement.

Un objectif secondaire de l'étude était de déterminer le type de relation qui pouvait exister entre la nappe d'eau perchée associée au dôme d'une tourbière ombrotrophe et la nappe potentiométrique du sous-sol rocheux.

La tourbière 569, d'une superficie de 290 ha, est située sur l'île de Lamèque, au nord-est du Nouveau-Brunswick. Cinquante hectares sont présentement exploités par la compagnie La Tourbe de Pigeon Hill Ltée. La tourbe est extraite par la méthode pneumatique et est destinée au marché de l'horticulture. La production annuelle est d'environ 125,000 ballots (environ 45,000 m^3 de tourbe brute récoltée). On trouve environ 2,2 millions de m^3 de tourbe in situ au-dessus du niveau du lac.

Le régime hydrologique de la tourbière a été évalué en mesurant la relation entre les précipitations, les niveaux d'eau phréatiques et les débits d'eau de surface pendant une période de trois mois à l'automne 1990. Les indices de qualité d'eau ont également été mesurés.

Une gamme variée d'instruments fut déployée de septembre à novembre 1990: 15 piezomètres pour observer les variations de niveau de la nappe d'eau; 7 déversoirs à

encoche en "V" pour mesurer les débits d'eau; et un pluviomètre. Pour plusieurs de ces instruments, les données furent recueillies à l'aide de collecteurs électroniques. De plus, des échantillonages d'eau ont été effectués afin de déterminer le pH et les quantitiés de matières en suspension dans l'eau.

Durant la période d'étude, on a dénoté 42 épisodes de précipitations sous forme de pluie, variant entre 0,2 mm et 75 mm. Les taux de ruissellement pendant la même période ont varié entre 0,00025 et 0,00050 $m^3/s/ha$ avec des valeurs de pointe variant entre 0,001 et 0,002 $m^3/s/ha$.

L'analyse détaillée des données de précipitations et de débits indique que le ruissellement est très influencé par les conditions antécédentes et l'intensité des précipitations. Les facteurs qui affectent le plus les débits sont: le niveau de la nappe phréatique dans la tourbière et le taux d'infiltration de l'eau dans la tourbe.

On a pu observer que le débit moyen quotidien était approximativement proportionel au niveau d'eau dans la tourbière (les débits augmentaient à mesure que le niveau de la nappe phréatique de la tourbière s'élevait).

Les débits de pointes correspondant à un épisode de précipitations peut être estimé à partir de la méthode "Rationnelle" modifiée:

$$Q = CIA$$

Q = débit (m^3/s)
I = intensité des précipitations (m/s)
A = superficie (m^2)

"C" est un coefficient de débit qui tient compte des caractéristiques d'une tourbière à l'aide de trois coefficients:

$C = C_1 \times C_2 \times C_3$

C_1 = un facteur relié au niveau de la nappe phréatique dans la tourbière (0,05 est bas; 1,0 correspond à une tourbière complètement saturée).

C_2 = un facteur relié à la capacité d'infiltration des précipitations (0,5 pour les pluies de faible intensité; 1,0 pour les pluies de forte intensité).

C_3 = un facteur correspondant aux conditions de surface et au niveau de développement de la tourbière. Un facteur de 0,5 a été choisi dans le cas présent.

Durant la période d'étude, la valeur de "C" a varié entre 0,02 et 0,16. Les variations pour C_1 et C_2 furent 0,5 - 1,0 et 0,05 - 0,95 respectivement. La valeur maximale de "C" pour Pigeon Hill serait 0,5 dans des conditions saturées et de précipitations intenses.

Deux systèmes de nappes d'eau ont été observées. Le système supérieur se trouve dans la tourbe. Le système inférieur est localisé dans le sous-sol rocheux, sous la tourbière. La nappe potentiométrique dans la roche est située environ 2 m sous celle présente dans la tourbière. Les deux systèmes sont complètement séparés par une couche imperméable de diamicton glaciaire. Les deux systèmes sont donc indépendants l'un de l'autre.

Des échantillons d'eau de surface ont été obtenus chaque semaine aux 7 déversoirs. On a mesuré le taux de matières en suspension et le pH (acidité) de ces échantillons.

Les niveaux de particules solides en suspension variaient entre 0,5 et 104 mg/l. Une valeur de 20 mg/l est considérée comme le maximum acceptable au point de vue impact environnemental. Le poids sec total de matières évacuées pour une surface de 124,4 ha

a été calculé à 820 kg pour la période du 7 octobre au 27 novembre 1990. On a trouvé que les concentrations de solides ne sont pas reliées aux débits de surface ou à la vitesse de l'écoulement mais probablement à d'autres facteurs tels que la construction et l'entretien des canaux de drainage, les facteurs opérationels et les facteurs environnementaux tel que le vent.

Des tests en laboratoire sur des échantillons de tourbe extraite indiquent que les caractéristiques de sédimentation de la tourbe dans l'eau sont influencées par la dimension des particules, le niveau d'humidité et la densité. La tourbe sèche tend à flotter jusqu'à ce qu'elle soit complètement humide. Cela prend plus de temps à mouiller les grosses particules que les petites; les petites particules se déposent donc les premières.

L'acidité des eaux de drainage variait entre pH 4,20 et pH 6,24. En général, les valeurs les plus basses (pH 4,20 - 4,8) correspondaient aux endroits à proximité des zones développées. Les valeurs plus hautes sont probablement dues à l'influence des sols minéraux exposés dans certains fossés. La valeur des pH tendait à augmenter avec le temps, dû peut être au facteur de dilution relié à des précipitations abondantes.

La construction de bassins de sédimentation peut éliminer les matières en suspension des eaux de drainage. Les dimensions de ces bassins peuvent être déterminées à partir des données recueillies durant l'étude. Cependant, des données additionnelles seront nécessaire pour confirmer l'efficacité de ces systèmes. Pour une surface de 50 ha, un bassin de 70 m de long par 5 m de large et 2 m de profondeur est nécessaire (nettoyé deux fois par année).

Certain éléments peuvent être ajoutés aux bassins pour en améliorer la performance: des mécanismes contribuant à mouiller les particules en créant de la turbulence; une estacade à la sortie pour retenir les particules flottantes de tourbe.

La planification et la construction de bassins appropriés pourrait faire l'objet d'autres études. Ces études devraient comprendre une évaluation des taux de matières en suspension évacuées des tourbières commerciales (mesures périodiques). Des analyses supplémentaires en laboratoire pourraient aider à mieux comprendre les caractéristiques de sédimentation de la tourbe. Il serait également utile de raffiner le présent modèle hydrologique en mesurant les débits sur d'autres tourbières.

Peatland Hydrology

Bog 569

Pigeon Hill, New Brunswick

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Peatland Hydrology

Bog 569

Pigeon Hill, New Brunswick

1. INTRODUCTION

The draining of peatlands for peat production can result in degraded runoff water quality. The degradation is characterized by increased suspended solids, increased dissolved organic carbon and reduced pH. Without mitigation, these problems are perceived to have major environmental implications on downstream aquatic ecosystems. This study was solicited by the New Brunswick Department of Natural Resources to address some of the issues involved in peatland development.

The medium sized (290 ha) peat bog selected for the study is located on the island of Lameque in northeastern New Brunswick (Figure 1.1). A fifty hectare portion of it is currently operated by La Tourbe de Pigeon Hill Ltee. for horticultural purposes; with harvesting being by the vacuum method. The annual production rate is approximately 125,000 bales or, in loose form, 45,000 cubic metres. An estimated 2.2 million cubic metres of peat occurs above the level of the lake within the bog (DNR, 1977).

The hydrology of the bog was evaluated by examining the relationship between precipitation, groundwater levels, and surface water flow rates and quality, in a three month period in the fall of 1990. A simple model has been developed to describe this relationship. This report describes our findings.

FIGURE 1.1 STUDY LOCATION PLAN

2. SITE CONDITIONS

2.1 Topography

The island of Lameque is relatively flat, with surface elevations varying from zero to 20 metres above mean sea level (asl). The peatland investigated here is located at the northern tip of the island. It comprises three small domes with interconnected areas of shallow peat. The largest of the domes, complete with a central lake, is at the south-west end of the peatland. The surface elevations, at a little over 8 metres above sea level, are at their highest here although the grade rises to 20 or so metres further south, beyond the limits of the bog.

The two smaller bogs which occur to the north and east of the peat plant, are being eroded by the sea resulting in formation of peat cliffs. The surface elevations here are less than 4 metres asl. Surface contours based on photogrammetry and on cross sections made by others (DNR, 1977) are shown in Figure 2.1.

2.2 Geology

2.2.1 Peat

Bog 569 is an ombrotrophic or raised peat deposit which has developed as a result of sphagnum encroachment in a shallow lake environment. Three domes have formed over undulating terrain. Peat thicknesses are variable and mineral islands protrude through the peat layer in some areas.

The thickness of the peat varies from less than one metre to a little over four metres based on probings made by others, as shown in Figure 2.2. The peat thickness was confirmed by Hiller sampler at each of the piezometer locations selected as part of this study. At these locations it varied from 1.4 metres (hole P10) to 3.7 metres (hole P3).

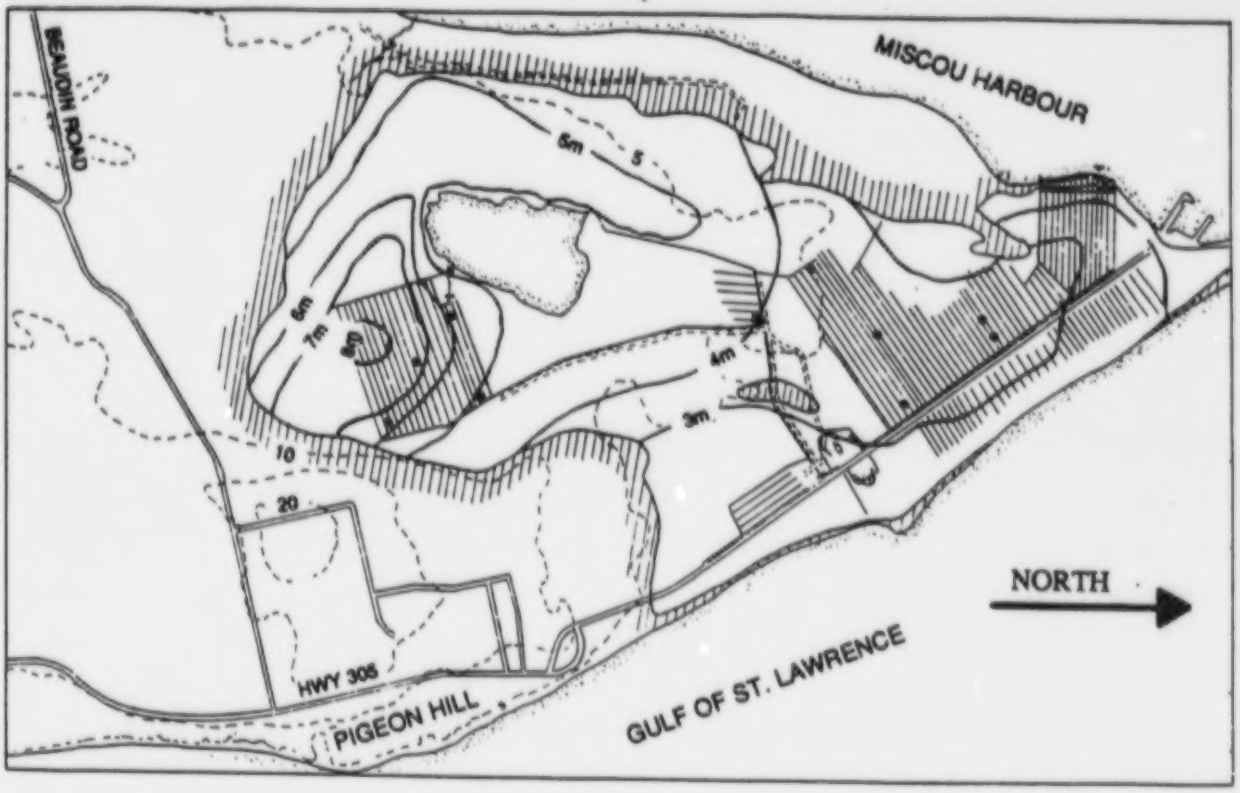

FIGURE 2.1 TOPOGRAPHY

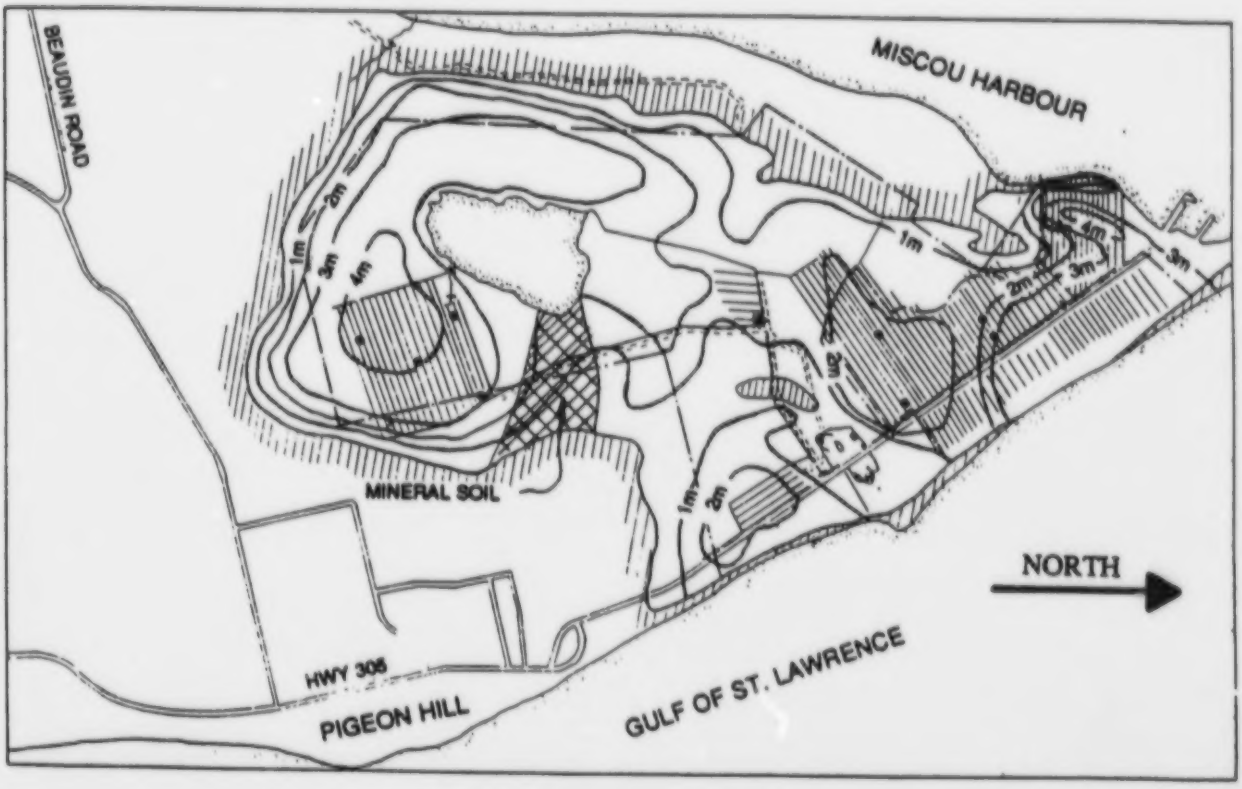

FIGURE 2.2 PEAT DISTRIBUTION & THICKNESS

Source: DNR.(1977)

DNR (1977) describe the deposit as comprising a one to three metre layer of poorly humified sphagnum peat of which shrubby-sphagnum is the predominant type. Thin basal layers of sedge peats composed of Carex with sphagnum, shrubs and some woody remnants, occur at depth. The lower one to three metres is described as well humified. A 70 cm thick basal ooze layer reportedly occurs under the western dome.

2.2.2 Mineral soil

Two boreholes were drilled through the organic soils for the prime purpose of installing deeper piezometers in the bedrock. At hole P3, drilled in the centre of the northern field, 3.7 metres of peat overlies 0.3 metres of fine sand which in turn rests on 0.6 metres of glacial till. Similar soils were encountered at P9 located 1,800 metres to the north. The fine sand occurred between the peat and glacial till at Weirs W-3, W-6 and W-7. Its erosion has resulted in undercutting of the ditches in many places and let to stream bank instability. Sandstone bedrock was encountered immediately beneath the till in both boreholes. Logs for the 14 holes are illustrated in Appendix E.

2.2.3 Bedrock

Rock was cored at HQ size at locations P-3d and P-9d. The rock is a medium grained sandstone, characterized by subhorizontal bedding joints spaced at about 50 mm and by a Rock Quality Designation, RQD, of less than 10 percent. RQD is described in Appendix F.

2.3 Climate

The climate of northeastern New Brunswick is mid latitude continental, with an annual precipitation of about 1000 mm of which 280 mm occurs between November and April as snowfall. Mean monthly temperatures vary from -11.3 °C in February to 20.1 °C in August.

3. FIELD DATA COLLECTION

3.1 Precipitation

A tipping-bucket rain gauge with chart recorder was installed in the village of Pigeon Hill approximately two kilometres south-east of the bog, as indicated in Figure 3.1. Closer sites were originally considered but were rejected because it was feared that air-borne peat fibres from the farming operation might interfere with gauge operation. Charts were replaced daily by a local individual. The date and time of each tip of the bucket, which signalled each 0.2 mm increment of rainfall, was manually transferred from chart to computer spreadsheet.

The precipitation data are plotted graphically beneath the associated streamflows in Figure 3.2. A total of 42 rainfall events were distinguished in the monitoring period. The intensity and duration of each event are given in Appendix A (Table A-1).

Figure 3.3 shows the precipitation data plotted on a daily basis, compared with those for two adjacent weather stations and for the more distant City of Bathurst. These values are also tabulated in Appendix A (Table A-2).

From Figure 3.3 it appears that rainfall data from the adjacent stations, for which a longer period of record is available, might reasonably be applied to the investigated bog. These data were also utilized to correct the Pigeon Hill rainfall record on several occasions, made necessary as a result of malfunctioning of the gauge.

Seasonal precipitation variations might be assessed from the Bathurst data which include mean monthly values not available for the closer stations. These mean values are shown graphically in Figure 3.4 and tabulated in Appendix A (Table A-3).

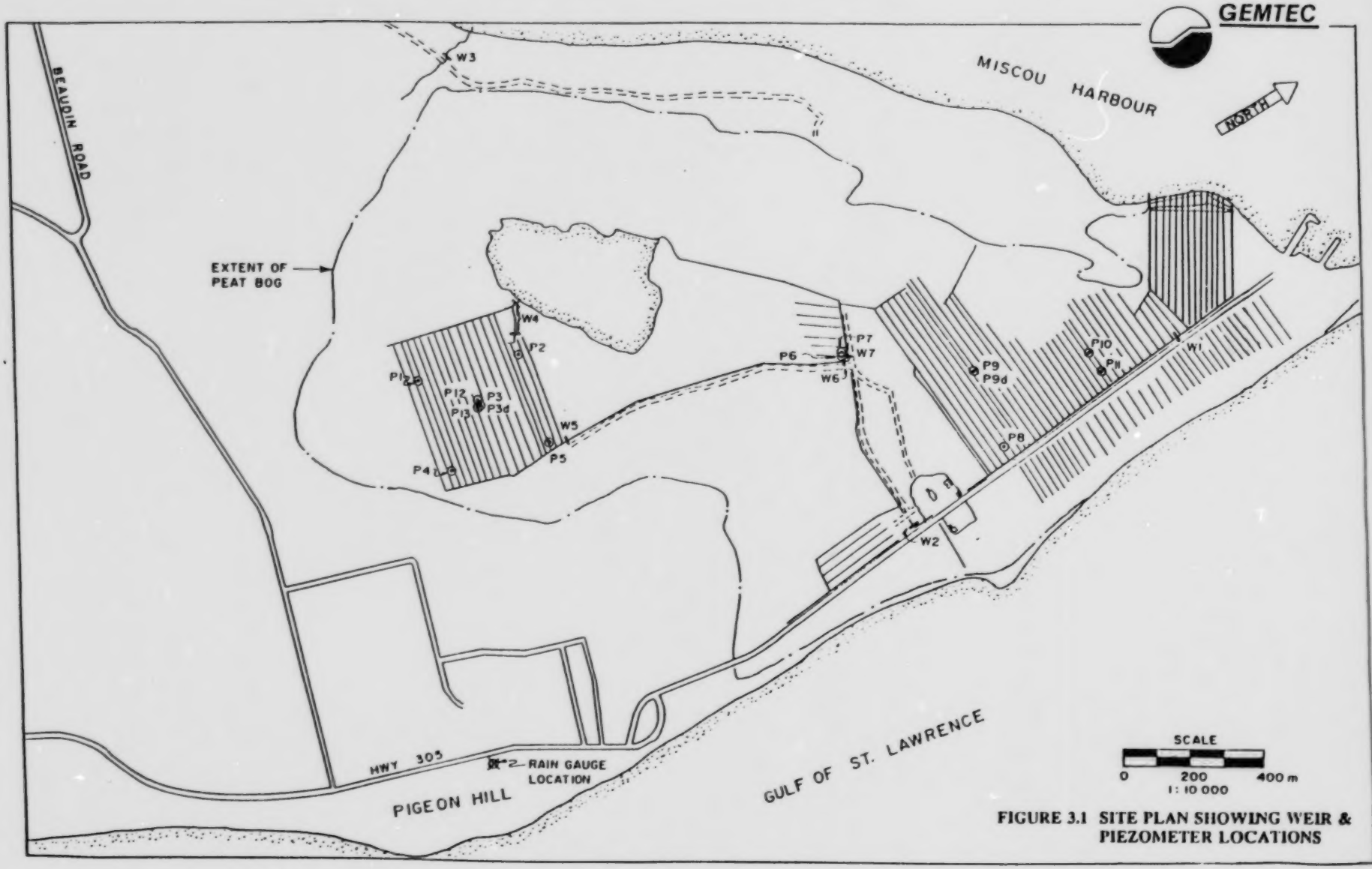

FIGURE 3.1 SITE PLAN SHOWING WEIR & PIEZOMETER LOCATIONS

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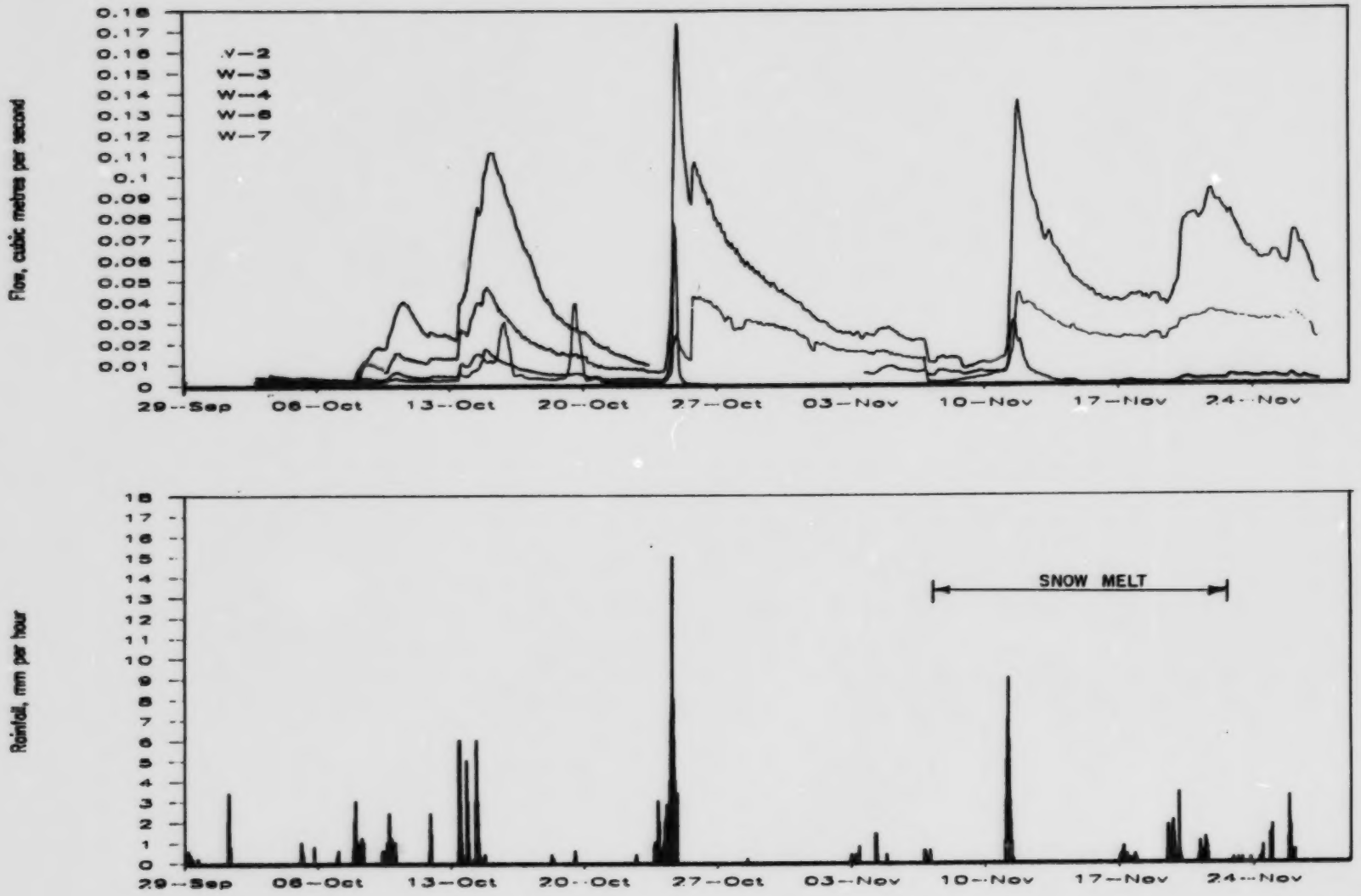


FIGURE 3.2 STREAMFLOW AND PRECIPITATION DATA - BOG 569

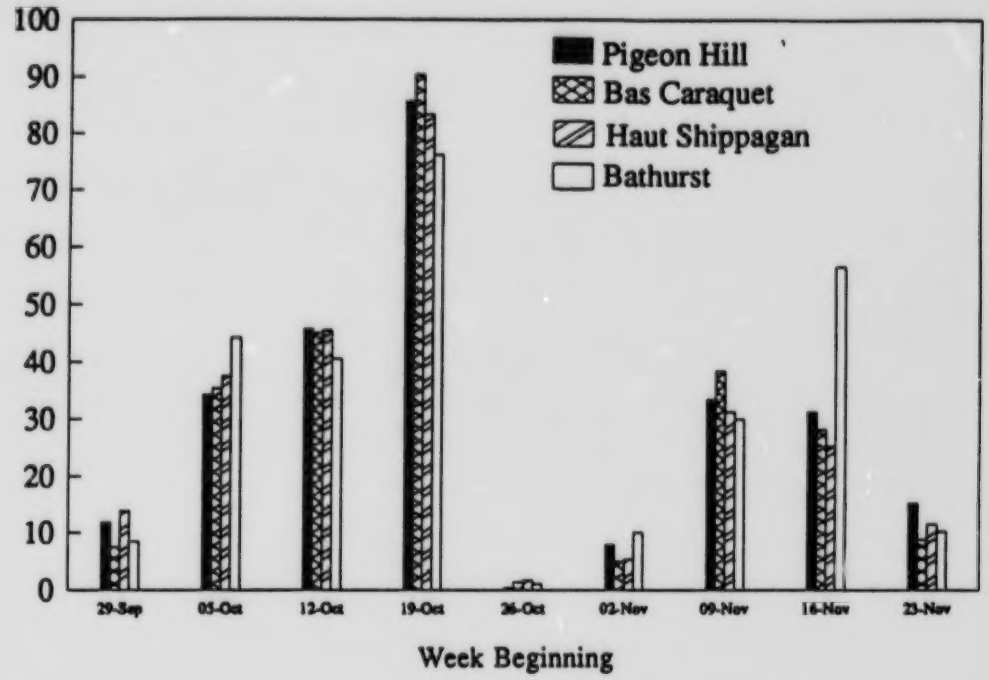


FIGURE 3.3 WEEKLY RAINFALL - BOG 569 AND NEARBY WEATHER STATIONS

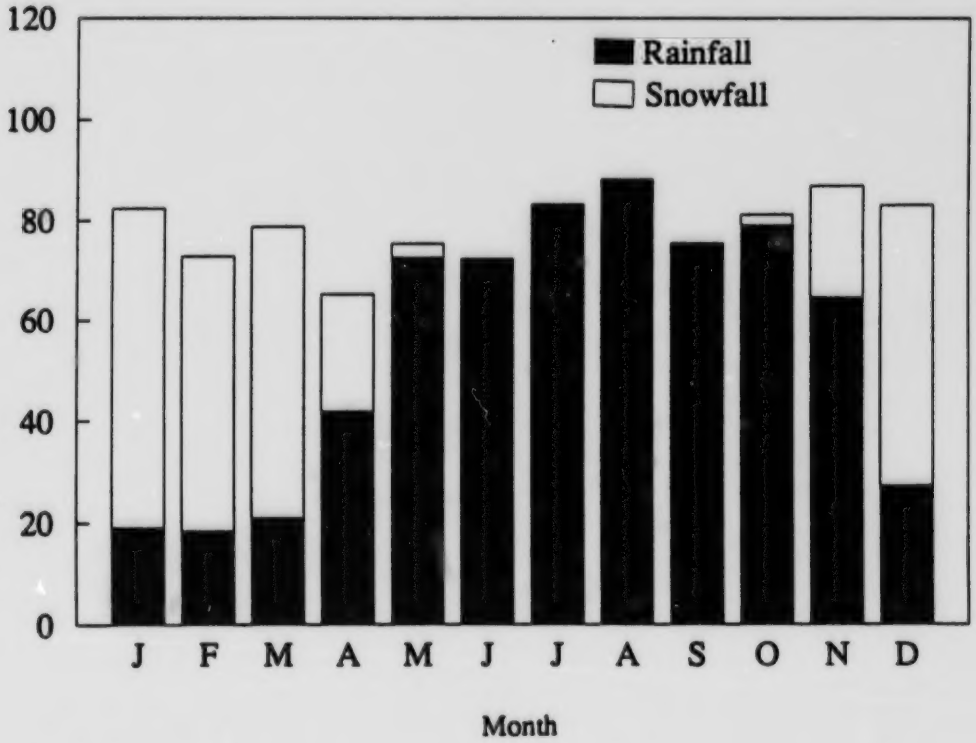


FIGURE 3.4 MEAN MONTHLY PRECIPITATION, BATHURST, N.B.

3.2 Stream-flow

Seven V-notch weirs were installed at strategic locations shown in Figure 3.1 to permit measurement of stream discharge in both developed and undeveloped parts of the study area. At five of the weirs, W-2, W-3, W-4, W-6 and W-7, vibrating wire pressure transducers and data-loggers were installed for the automatic recording of discharge heads and therefore flows.

The mean monthly precipitation for this region is remarkably uniform at about 80 millimetres. Most water would be available in the spring, however, when the naturally high rainfall is supplemented by considerable snow-melt.

Two weirs were eventually lost during the study; W-3 to extensive washout following the largest of the rains, and W-1 removed at the request of the peat operator who felt it was interfering with field drainage. Details of the weirs and data loggers are given in Appendices B and C.

Figure 3.2 shows stream flow data and the precipitation record for a substantial part of the data acquisition period. Three approximately equal sections of the record can be identified. Low stream flows attributed to the groundwater contribution of baseflow;, occurred prior to the first substantial rainfall event of October 7, 1990. The stream hydrographs responded quite quickly to this event, with peak discharges occurring within 20 hours of the onset of rainfall. The subsequent event of October 9, 1990 was similar in magnitude and duration but produced a much greater discharge response. Considerable rainfall occurring some four days later resulted in a further threefold increase in peak flow. Stream discharges then decayed exponentially but were still 20 times those of the original "base-flow." values, immediately prior to the rain of October 24.

The mid-section of the hydrographic record begins with the October 24, 1990 event which had an average intensity of 2.92 mm per hour over a total duration of 29 hours, and a

peak intensity of 15 mm per hour. The resulting peak stream flows were the highest recorded in the period of observation, and although flow rates had declined substantially in the two weeks which elapsed before the next significant rainfall event of November 11, the more slowly released groundwater component identified by the flatter portion of the curve, had again increased.

The third and final section of the record begins with the November 11 event, followed up by low intensity but persistent showers and intermittent snowfall. Again, the base flow contribution appears to be considerably higher than might have been anticipated as a result of comparable rainfall had they occurred earlier on in the season, or by inference, in summer months.

Occasional unexplained fluctuations in streamflow occurred in the period of record, most notably those for Weir W-7 on October 15 and 19, 1990. It seems likely that such fluctuations were real ones, probably caused by upstream ditching activity

Not shown in Figure 3.2 would be additions to the available water balance made by snowmelt towards the end of the field observation period, for example, an estimated 9 mm of snowmelt contributed to the measured streamflows.

A more detailed analysis of these data follows in Sections 5 and 6.

3.3 Water Quality

Surface water samples were taken at the installed weir locations on a total of seven occasions. Tables 3.1 and 3.2 show the results of suspended solids and pH analyses respectively.

TABLE 3.1 TOTAL SUSPENDED SOLIDS - SURFACE WATER SAMPLES
TSS EXPRESSED IN mg/l

Sample Location	Sampling Date Oct. 9	Oct. 16	Oct. 23	Oct. 31	Nov. 8	Nov. 16	Nov. 27	Avg
W 1	104	12	13	7.2	-	-	-	-
W 2	11	1.7	7.5	2.3	2.6	4.8	3.8	4.8
W 3	4.4	1.3	1.6	-	-	-	-	
W 4	1.8	1.9	2.6	0.5	-	3.8	94.3	
W 5	1.9	2.6	21	27	-	2.0	0.9	9.2
W 6	11	5.9	18	4.4	9.9	8.2	7.6	9.3
W 7	1.0	0.5	0.6	5.5	0.7	8.3	10.8	3.9

TABLE 3.2 pH - SURFACE WATER SAMPLES

Sample Location	Sampling Date Oct. 9	Oct. 16	Oct. 23	Oct. 31	Nov. 8	Nov. 16	Nov. 27	Avg
W 1	4.25	4.39	4.55	4.55	-	-	-	4.44
W 2	6.02	5.06	5.82	5.32	-	-	5.35	5.51
W 3	5.98	5.93	5.91	-	-	-	5.94	5.94
W 4	4.20	4.32	4.30	4.50	-	-	4.82	4.42
W 5	4.33	4.44	4.69	4.65	-	-	4.89	4.61
W 6	6.42	5.81	6.18	6.17	-	-	6.44	6.20
W 7	4.32	4.25	4.39	4.67	-	-	4.80	4.49

3.3.1 Suspended Solids Data

Total suspended solids varied from 0.5 to 104 mg/l while the mean value was 10.7 mg/l. A value of 20 mg/l is customarily regarded as high from the point of view of potential detrimental impact on downstream aquatic systems.

These data compare with values from High Point Bog in Newfoundland (Monenco, 1986) where the suspended solids varied from 1 to 52 mg/l and the mean was 3 mg/l. Dramatically higher suspended solid results for a mined field were reported for a peat bog in North Carolina (Gregory, et al., 1984). In that study, suspended solids varied from 105 to 401 and averaged 318.8 mg/l. Selin, et al., (1984) reported that suspended solids may rise to 2000 mg/l at times of ditch construction. The bogs in North Carolina are typically minerotrophic, composed primarily of Carex peats. This peat is more decomposed than the sphagnum peat found in the ombrotrophic bogs of northeastern New Brunswick.

From Table 3.2, it appears that the surface water in those ditches closest to mined fields (e.g., W-1, W-5) have higher suspended solid contents than do ditches further from active development. This trend,which is reported by others (Gregory, et al., 1984) is presumably due to settling of the suspended solids load with transportation along the ditches, in additions to dilution effects from surface water originating in unmined areas.

3.3.2 Acidity Data

Surface water pH values, shown in Table 3.3, varied from 4.20 to 6.42; being lowest at locations such as Weirs W-1, W-4 and W-5 situated close to the actively mined area. Higher pH values were consistently obtained for surface waters at Weirs W-2 and W-6, reflecting the significant contributions of water from mineral-soil areas. By way of comparison, Monenco (1981) report typical surface water pH values varying between 3 and 4.5 for ombrotrophic sphagnum bogs.

The two primary mechanisms by which pH is increased are 1) dissolution of minerals (carbonate, feldspars, etc). and 2) oxidation of organic matter (and subsequent venting of CO_2).

The primary sources of acidity in organic waters are humic and fulvic acids. Humic and fulvic acids are general terms that cover a wide range of organic compounds. Humic acid precipitates from solution at a pH below 2 and fulvic acid is soluble across the pH range.

The dissolution method can be simply described as the CO_3^- from calcite or dolomite (within the soil), combining with H^+ from the acids to form HCO_3, thereby reducing the acidity of the water.

Oxidation occurs as O_2 combines with C from the water to form CO_2. If the carbon dioxide is not vented sufficiently from the water an additional reaction may occur where CO_2 combines with free H^+ to form H_2CO_3 (carbonic acid). In this case, the pH of the water would actually decrease.

It is believed that the dissolution process is infinitely more important than the oxidation process, in this case. This is substantiated by field results. Water passing over Weirs W-6 and W-7 follows similar paths (length of travel, turbidity, etc.) except that water at W-6 has had substantial contact with mineral soils which contain carbonates, feldspars, etc. The pH value at W-6 is 6.20 as compared to 4.49 for W-7. Water pH was 4.40 at Weir W-4 closest to the farmed area.

3.4 Groundwater

3.4.1 Groundwater Levels

A total of 15 piezometers were installed at locations shown in Figure 3.1. Most were screened for a considerable part of their total penetration in peat. Others were screened so as to permit detection of vertical gradients within the peat. Two piezometers (P3D and P9D) were installed and sealed in the underlying bedrock.

Vibrating wire pressure transducers coupled to automatic data loggers were installed in the shallow and deep piezometers P3 and P3D in the middle of the southern field. An intermittent record of water levels was obtained, as shown in Figure 3.5. Water levels in other piezometers were determined manually.

The perched nature of the bog water table is immediately apparent from Figure 3.5. Water levels in the bedrock system were consistently two to four metres lower than those in the overlying peat. Both potentiometric surfaces fluctuated within about a one half metre range over the period of record. The shallow water table at P3 was approximately about 200 mm higher at the end of the observation period than at the beginning. The rise in the deeper potentiometric surface in this period was perceptible but less pronounced.

Groundwater flow directions for the north field are shown in Appendix D. Groundwater profiles indicate drainage towards the lake. Groundwater flow, in general, should follow the gradient of underlying material soil.

3.4.2 Glover-Dumm Model for Effect of Ditching on Water Table

The relationship between ditch geometry, peat characteristics and the time required for drainage has been investigated by others (Muzik, 1982).

GEMTEC

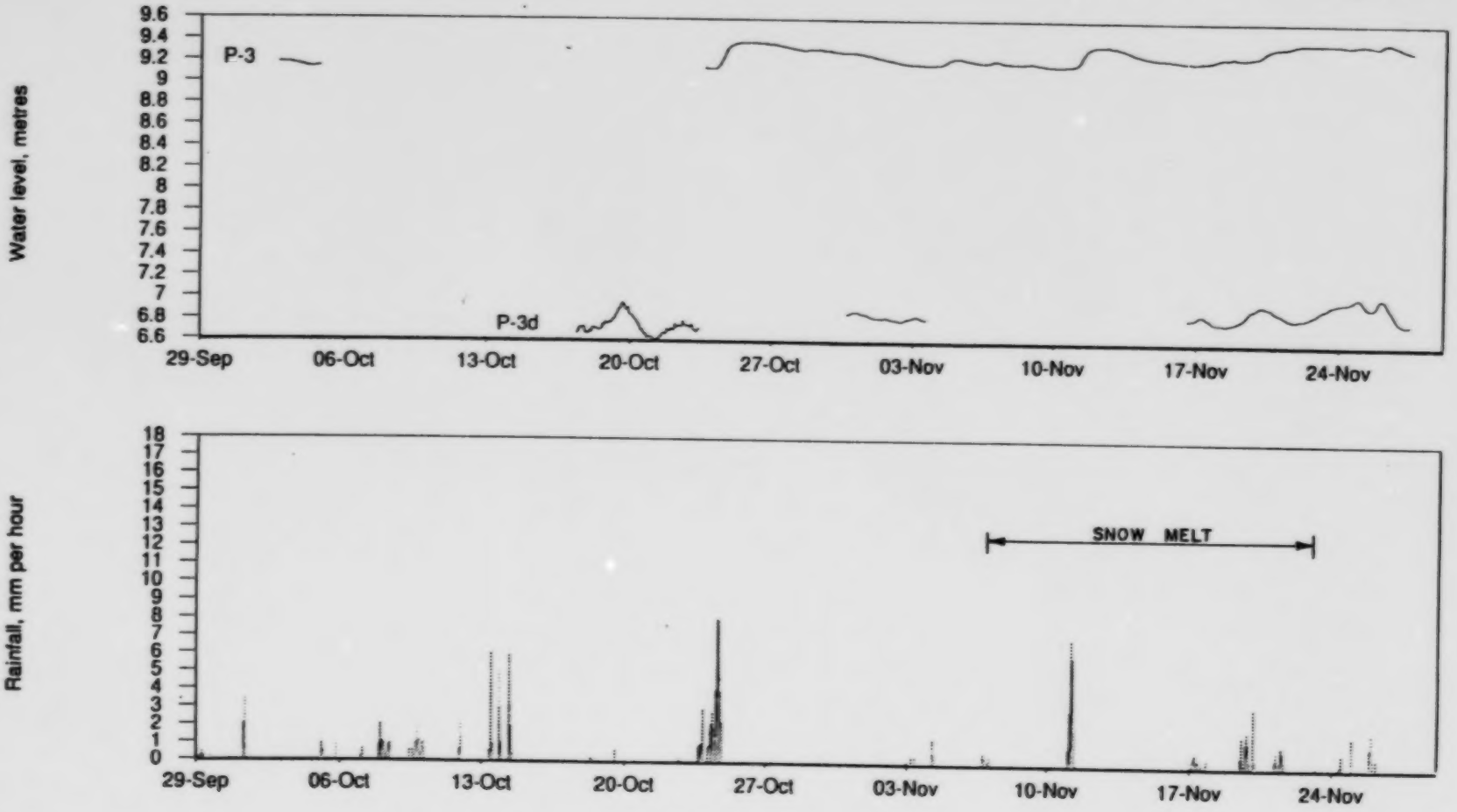


FIGURE 3.5 GROUNDWATER LEVELS AND PRECIPITATION DATA - BOG 569

One such relationship is the modified Glover-Dumm equation (Wesseling, 1973):

$$Ld = \pi (Kdt/\mu)^{1/2} \cdot (\ln \cdot 1.16\ h_o/h_t)^{-1/2} \quad \text{.....Equation 3.1}$$

in which Ld is the drain spacing (m); K the hydraulic conductivity (m/day); d the depth of water in ditches dug to an impermeable layer; μ the drainable pore space (m/m); h_o the total drawdown achieved at the ditches in metres, and h_t the height of the groundwater table above the water level in the ditches and (t) the days after ditch construction. Figure 3.6 shows the assumed boundary conditions.

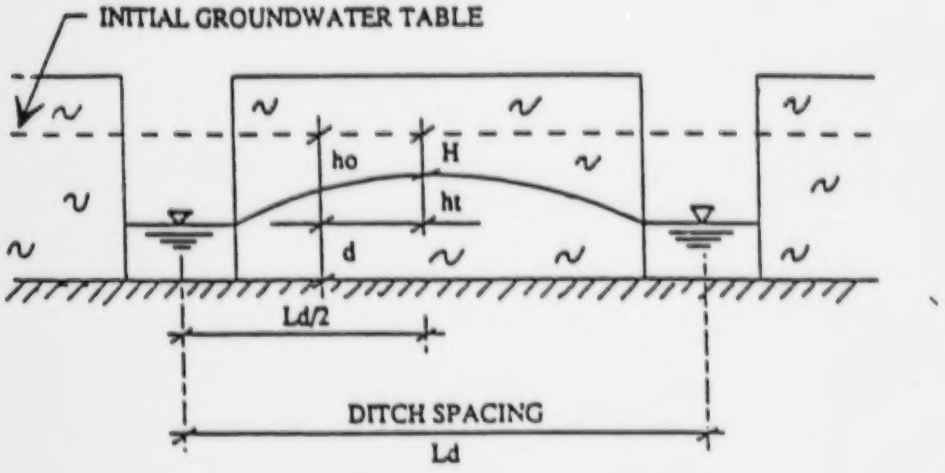


FIGURE 3.6 BOUNDARY CONDITIONS FOR THE GLOVER-DUMM EQUATION

The modified Glover-Dumm equation can be re-arranged to

$$H = h_o \left[1 - \frac{1.16}{e^{\left[\pi \frac{\sqrt{\frac{Kdt}{\mu}}}{La} \right]^2}} \right] \quad \text{.....Equation 3.2}$$

Figure 3.7 shows the time-drawdown relationship for a specific ditch geometry comparable with that at Pigeon Hill, based on Equation 3.2.

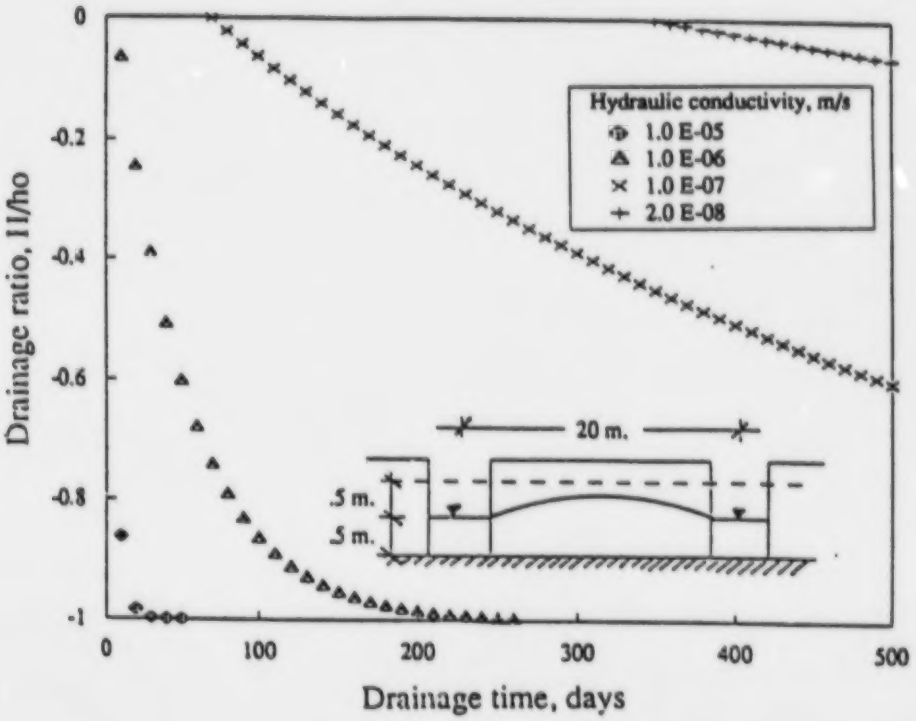


FIGURE 3.7 EFFECT OF HYDRAULIC CONDUCTIVITY ON DRAINAGE TIME, USING THE GLOVER-DUMM EQUATION

The time required for groundwater levels between ditches to drop a certain percentage of the available drawdown, varies inversely with the hydraulic conductivity. In the above example, a drop in water level of 5 cm, or 10 % of the available drawdown, for example, would require 1.2, 12 or 120 days for peat hydraulic conductivities of 10^{-5}, 10^{-6} and 10^{-7} m/s, respectively.

An average value of the hydraulic conductivity of the peat can therefore be estimated by examining the response of the bog water levels to variations in recharge. Figure 3.7 shows that, in between rainfall events, the water level was fairly stable, dropping with time almost imperceptibly at perhaps 10 mm per day. Using the Glover-Dumm model, the implied hydraulic conductivity would be approximately 1×10^{-7} m/s. Figure 3.5 shows the 180 mm rise in bog water level which occurred about 30 hours after the beginning of the rainfall event. Bog water level then dropped to its pre-rainfall level in a further 288 hours. Again utilizing the Glover-Dumm approach, these data suggest that the hydraulic conductivity of the peat at shallow depth is of the order of 1×10^{-5} m/s; considerably higher than that at greater depth. This is in general agreement with the conclusions of other researchers; that is, that the hydraulic conductivity of peat bogs decreases exponentially with depth (Goode, et al., 1977).

The concept of an upper, "active" layer of the bog, within which most moisture exchange takes place, has been proposed by Soviet researchers (Ivanov [1953] and Romanov [1953, 1969]) and discussed by Goode, et al., (1977).

3.4.3 Relationship between Perched and Bedrock Water Tables

By definition, an ombrotrophic or perched bog is independent of the underground flow systems. Figure 2 in Appendix E illustrates the assumed geometry through the south field at piezometer P3d.

The perched water table in the bog is approximately 2 metres higher than the potentiometric surface in the bedrock (Figure 3.5). Nevertheless, the contribution to bedrock water from the perched water table is probably very small.

Firstly, the downward hydraulic gradient between the top and bottom layers of the peat proved to be negligible. This was determined upon installing two piezometers (P12 and P13) at different depths. The water level was essentially the same in the two piezometers,

indicating a negligible downward hydraulic gradient. Secondly, both the peat and the underlying glacial till soils have low hydraulic conductivities. An hydraulic conductivity of 7.5 x 10^{-8} m/s has been reported for dense decomposed peat (Radforth and Brawner). A liberal estimate of hydraulic conductivity over the depth of peat would be 1 x 10^{-7} m/s. The hydraulic conductivity of the underlying glacial till is estimated to be 1 x 10^{-10} m/s, given its high clay content (Freeze and Cherry). From this, one might calculate the contribution of perched water to the bedrock as follows.

The flow (Q) through the peat and glacial till assuming geometry in Figure 2 in Appendix E is:

$Q = K \cdot h/l \cdot A$

Where Q = discharge m^3/s

h/l = hydraulic gradient

A = area = (1 m^2)

$Q_{peat} = 1 \times 10^{-7} \times 1 \times 1$

$= 1 \times 10^{-7}$ m^3/s

$Q_{till} = 1 \times 10^{-10} \times 4/1 \times 1$

$= 4 \times 10^{-10}$ m^3/s

Therefore the rate of leakage is controlled by the glacial till at 4 x 10^{-10} $m^3/s/m^2$ or 4/1000 of that which could escape from the peat if no till were present. This leakage rate would amount to 1.3 cm in a one-year period, which is practically negligible compared with the precipitation contributing to bedrock recharge in this period.

4. LABORATORY TESTING

Various laboratory tests were conducted to determine the physical properties of the Pigeon Hill sphagnum peat, including grain size analysis, moisture-density characteristics, hydraulic conductivity and field capacity. In addition, several simple tests were performed to qualitatively observe settling and wind transportation characteristics of the peat fibres.

4.1 Gradation

A bagged peat sample was dry sieved in accordance with ASTM D2977.71. The sample gradation is shown in Figure 4.1. The percentage by weight finer than the 0.080 mm mesh, that is to say, the silt size, proved to be 1.8 percent.

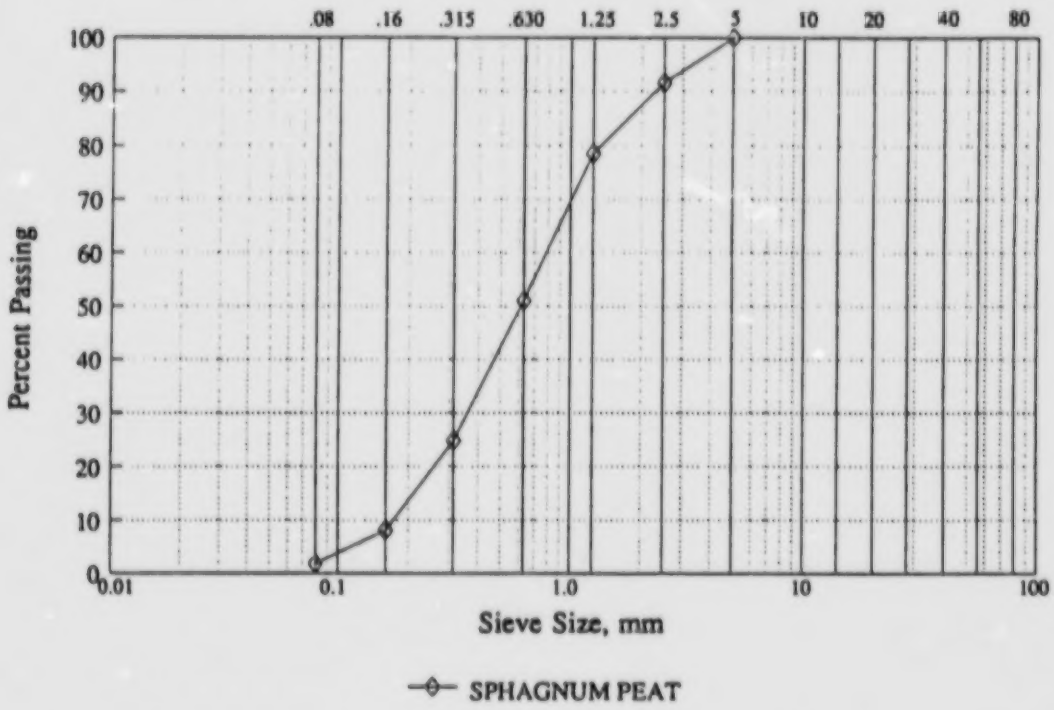


FIGURE 4.1 PARTICLE SIZE DISTRIBUTION SPHAGNUM PEAT - BOG 569

4.2 Moisture-Density Characteristics

The moisture content of peat varies in a wide range from hundreds to thousands of percent depending on peat character and the availability of water. Relatively dry processed peat from Pigeon Hill proved to have an "as received" moisture content of 150 percent, expressed as a percentage of dry weight. The saturated moisture content of this same material, placed in a rigid container with moderate compaction and then fully soaked, proved to be in excess of 1000 percent. Placed in a loose condition, the saturated moisture content exceeded 2500 percent.

For interest, a "conventional" Proctor density test was carried out on the same material. The compacted densities at three moisture contents are shown in Table 4.1 and plotted in Figure 4.2. Details of the Proctor Test are described in Appendix G.

In a less formal manner, relatively dry peat was compacted into a rigid container for determination of field capacity at each of two densities. The results are also summarized in Table 4.1 and plotted in Figure 4.2. In Table 4.2 the saturated moisture content was calculated using the following formula:

$$\rho d = \left[G_s/1+wG_s \right] \times \rho w$$

where ρd = zero air voids density
G_s = specific gravity (1.4)
w = water content
ρw = density of water

From this the "zero air voids" line can be drawn, and the correlating saturated moisture content chosen.

The first such sample (Test # 1) (Figure 4.3), compacted to a dry density of 0.07 t/m^3,

which was added to the top of the column soaked into the peat but there was no through-flow or discharge. The second 500 cubic centimetre flux caused further soaking but only very limited discharge. The field capacity had evidently been reached at this point, however, because subsequent increments of water at the top of the column were matched by equivalent discharges. The maximum moisture content or field capacity achieved after 50 minutes was 1192 percent which compares with the saturated moisture content at this density of 1356 percent. The degree of saturation was therefore about 88 percent after prolonged access to water at the surface. The implied hydraulic conductivity of this sample was 1 x 10^{-2} m/s. The progress of the test can by judged from Figure 4.3.

TABLE 4.1 MOISTURE-DENSITY RELATIONS AND FIELD CAPACITY - SPHAGNUM PEAT

TEST TYPE	DRY DENSITY t/m^3	MOISTURE CONTENT, %	FIELD CAPACITY %	SATURATED MOISTURE CONTENT % *	POROSITY n *	VOID RATIO e *
ASTM D-698	0.152	150	-	586	0.891	8.2
ASTM D-698	0.164	380	-	538	0.883	7.5
ASTM D-698	0.118	680	-	776	0.916	10.9
F. CAP. #1	0.070	151	1192	1356	0.950	19.0
F. CAP. #2	0.037	151	2550+	2625	0.974	36.7

* Assuming Gs peat = 1.4

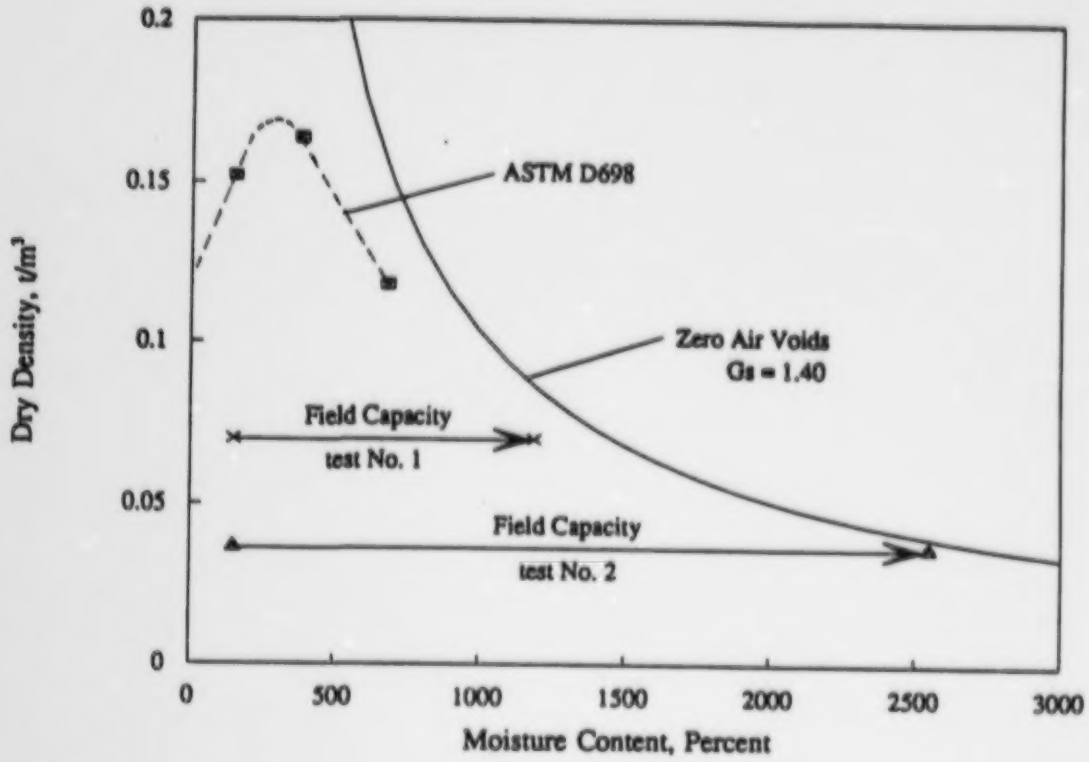
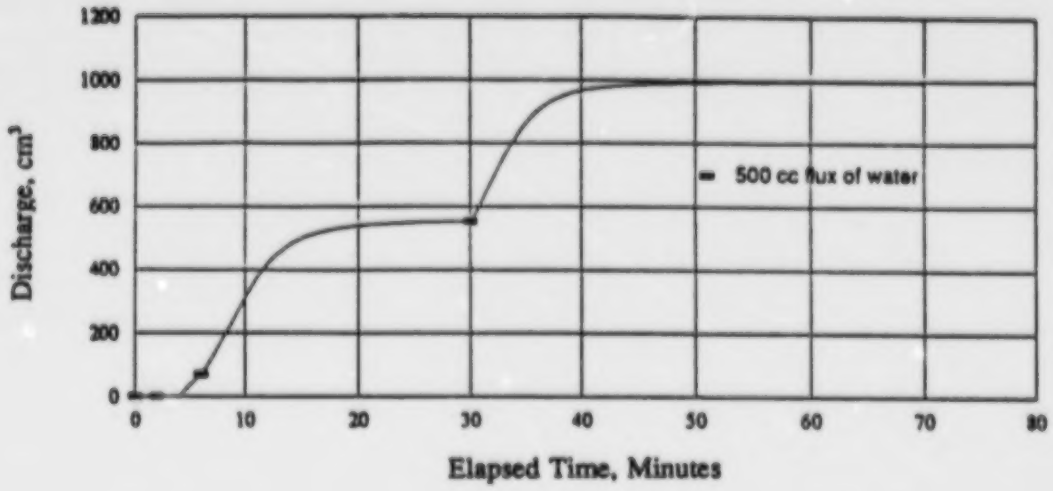
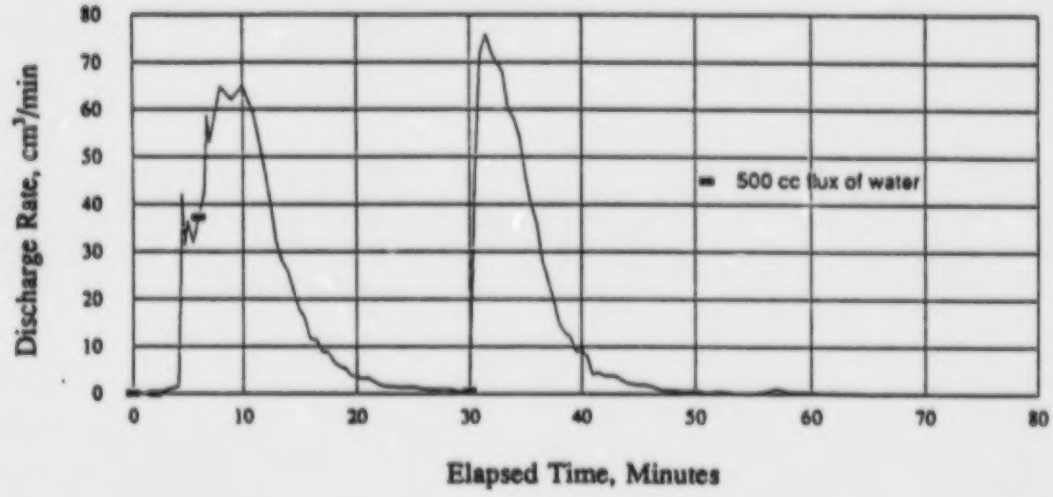


FIGURE 4.2 DRY DENSITY VERSUS MOISTURE CONTENT RECONSTITUTED SPHAGNUM PEAT





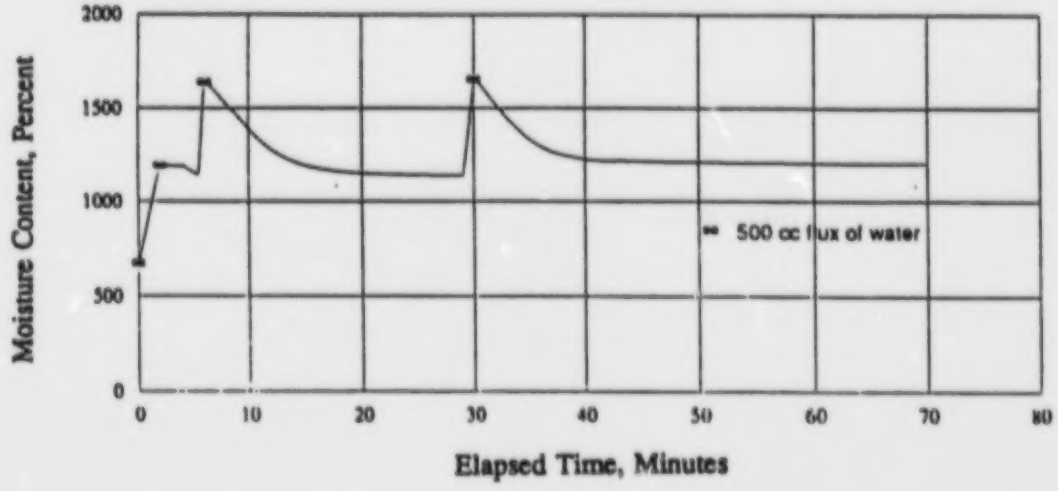


FIGURE 4.3 FIELD CAPACITY TEST ON RECONSTITUTED PEAT TEST No.1, DENSE CONDITION

A second field capacity test (Test # 2) (Figure 4.4) was carried out with the peat placed in an even looser condition. Similar behaviour was observed, with a moisture content of 2550 percent reached 30 minutes into the test after repeated increments of water being added at the surface. The field capacity might have proved to be higher than 2550 percent had the test continued.

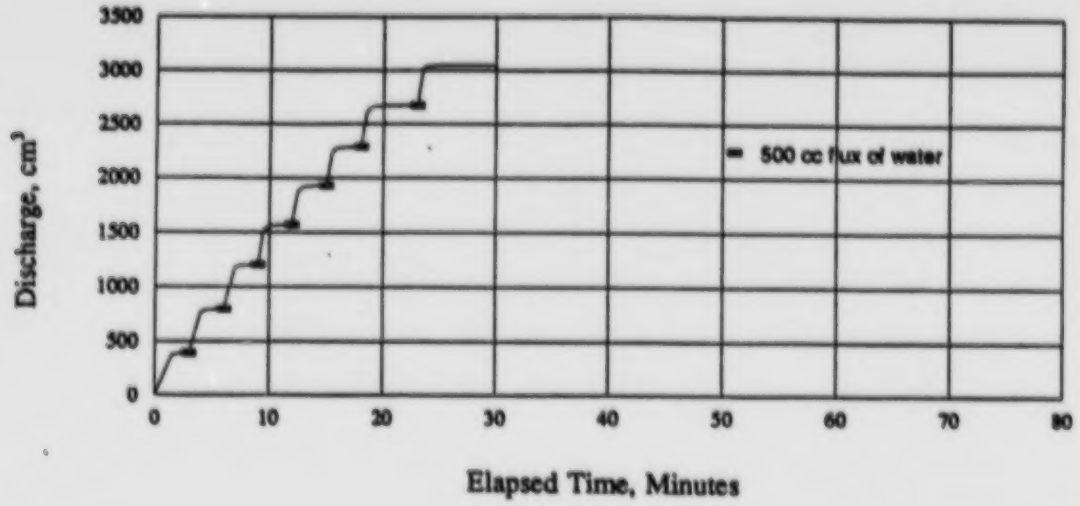
In both of the field capacity tests, the saturated front moved downwards through the peat column, eventually to stabilize at one level. Below this level, the peat is evidently saturated under capillary tension.

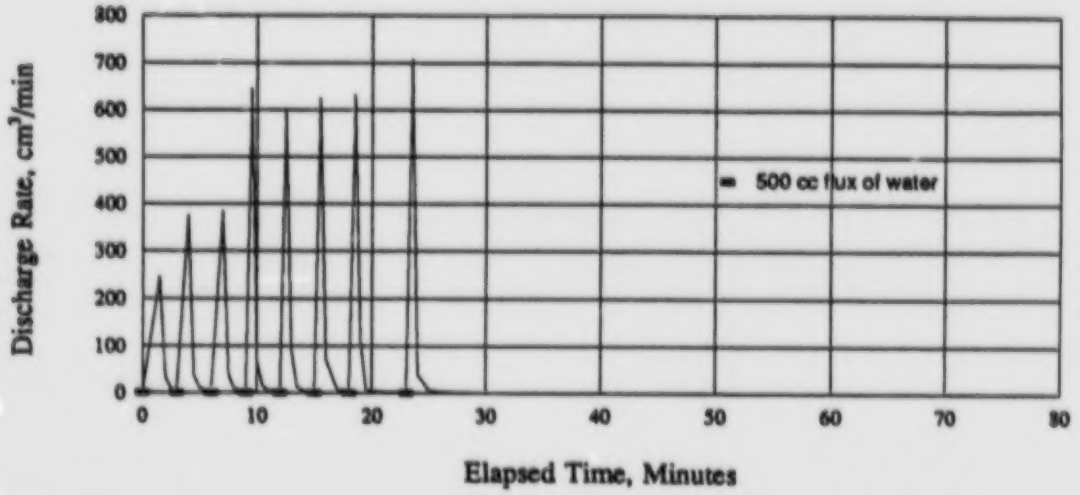
These field capacity tests are useful, if only qualitatively, in that they model the response of a peat body to a rainfall event. Provided the precipitation intensity is less than the infiltration capacity, initial rainfall will be absorbed by the surficial peat layers until field capacity is reached. Thereafter, rainfall will top-off the near-surface groundwater reservoir with the surplus running off. Significant runoff will only occur after this field capacity is reached, unless the rainfall intensity exceeds the ability of the peat to soak it up.

4.3 Settling Characteristics

Although the peat fibre specific gravity is known to be in the 1.2 to 1.8 range (Radforth, et al., 1977), dry peat is relatively buoyant, and conventional settling or hydrometer analyses have little application. A simple series of tests were carried out, however, to evaluate settling characteristics.

A number of size fractions of the peat (from the dry sieve analyses) were sprinkled on the surface of water in individual 250 ml beakers. One set of samples were left undisturbed for a 24 hour period, while the other set was agitated so as to thoroughly wet the peat fibres.





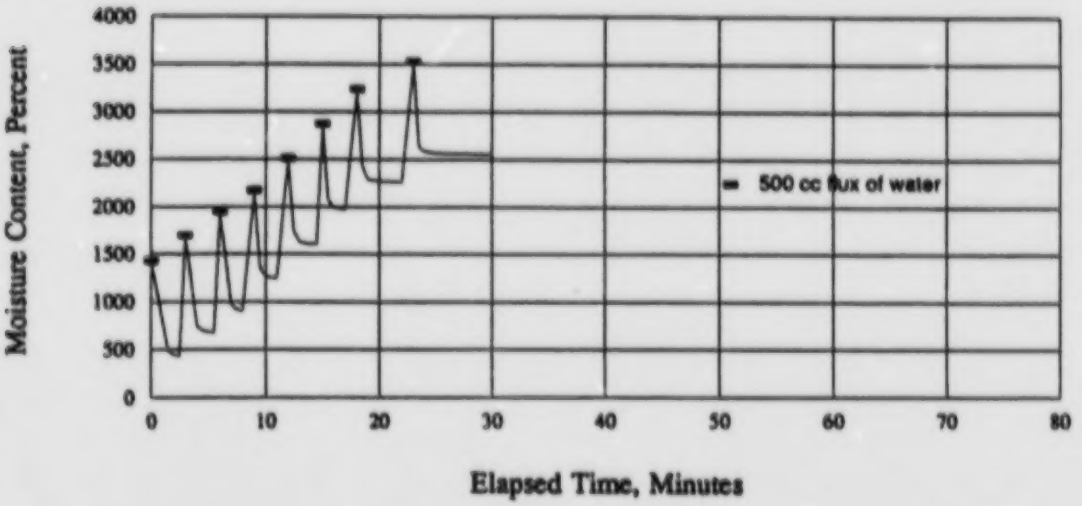


FIGURE 4.4 FIELD CAPACITY TEST ON RECONSTITUTED PEAT TEST No.2, LOOSE CONDITION

After a 24 hour period, the beakers were observed. Where no agitation had taken place, almost all of the peat fibres remained on the water surface, irrespective of fibre size. Where agitation had been employed, three fractions of the peat fibres were distinguished, these being the floating fraction, the suspended load and the settled component. The results are shown in Table 4.2.

TABLE 4.2 PERCENTAGE OF AGITATED PEAT IN VARIOUS SETTLING STAGES AFTER 24 HOURS, BASED ON DRY WEIGHT

Min. size, mm	2.5	1.25	.630	.315	.160	.080	0
Max. size, mm	5.0	2.5	1.25	0.630	0.315	0.160	0.080
Floating	94	90	90	80	78	58	42
Suspended	2	6	6	6	8	8	12
Settled	4	4	4	14	14	34	46
TOTAL	100	100	100	100	100	100	100

With conventional mineral soils, the larger particle sizes settle out first, in accordance with Stoke's Law. These simple experiments suggest that the reverse is true for peat fibre soils, presumably because the larger fibres contain air and therefore have lower apparent specific gravities than do the smaller fibres. Nearly one half of the silt size particles had settled out after 24 hours compared with only 4 percent for the larger fibres, most of which were still floating. The suspended solids load was relatively small in all cases.

4.4 Wind Blown Transport

When conditions are dry and windy, dust clouds are often visible above farmed peat bogs. Airborne transport is known to be a major mechanism whereby peat fibres are moved from the land surface to the adjacent bodies of water.

A very crude experiment was carried out in the laboratory to observe this phenomenon. Relatively dry peat, at a moisture content of 150 percent, was placed on a flat surface in front of a simple (1-3 m/s windspeed) ventilation fan. After turning the fan on, one hour elapsed before any significant peat movement was observed. Two hours into the test, approximately 20 percent of the peat by weight had been blown down-wind of its original location. Small particles did not seem to be significantly more mobile than the larger ones.

Perhaps predictably, the fan had the effect of first drying out the fibres and then transporting them when their individual masses were low enough to be readily transported.

5. ANALYSIS AND MODELLING

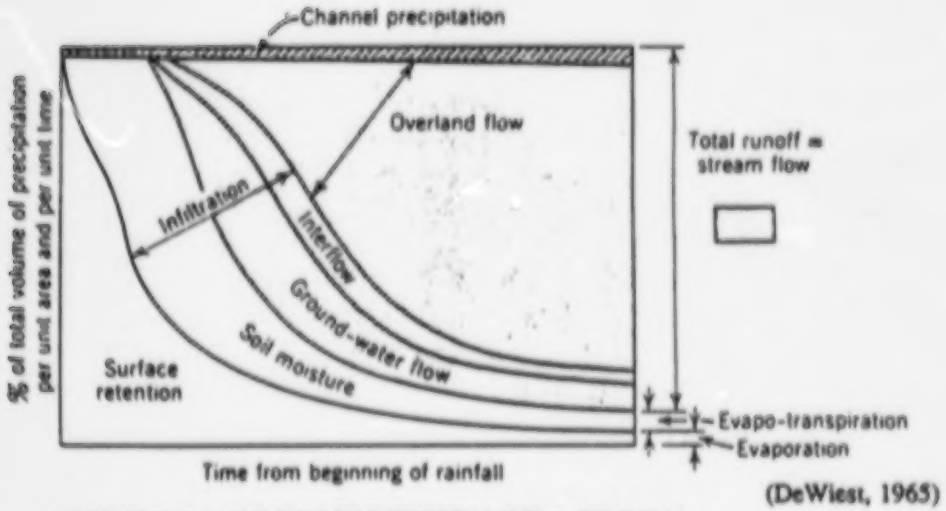
5.1 Hydrologic Regime

Run off or stream flow is normally considered to be the sum of surface runoff (termed overland flow until it reaches the stream) and groundwater discharge to the stream. At the beginning of a storm, much of the precipitation will be intercepted and stored in surface depressions or on the vegetation. Mild intensity, short duration storms may be entirely intercepted in this manner as surface retention.

With heavier rainfall events, vegetation is fully wetted and the surface depression storage becomes exhausted. Infiltration into the soil then occurs, first raising the moisture content in the unsaturated zone and then joining the groundwater system. Water which joins the groundwater system produces a rise in the water table and associated increases in hydraulic gradients and groundwater flow.

Figure 5.1 shows the relationship between surface retention,infiltration and overland flow during a storm of moderate intensity, as described by DeWiest (1965). A part of the rain falls directly into the stream channels and runs off - irrespective of the characteristics of the soil or vegetation. Almost all of the rain falling outside such channels is initially collected as surface retention. With time, infiltration begins and increases. Overland flow occurs when the rainfall intensity exceeds the infiltration capacity of the soil. With prolonged rainfall, the runoff becomes fairly constant as does the groundwater component or base flow.

Bay (1968) noted that water discharge from the Northern Minnesota peat deposits was closely related to the water table elevation in each bog. When the water level was above a site-specific 'critical' level, additional recharge water was temporarily stored and then made available for runoff. Rises in water table above the critical level resulted in exponential increases in runoff.



(DeWiest, 1965)

FIGURE 5.1 DECOMPOSITION OF A STORM OF UNIFORM INTENSITY

Lowering of the water table below the critical level occurred periodically due to evapotranspiration. Subsequent precipitation would go directly into storage until the water table rose to the critical level at which time runoff would resume.

Figure 5.2 shows the mean daily discharge at Weirs W-2, W-4 and W-7 plotted against the water table elevation in the middle of the largest developed field. Water levels were measured at P-3.

The mean daily flows have been normalized to the equivalent one hectare contribution by dividing each value by the appropriate drainage area. The bog water levels in Figure 5.2 are expressed in metres above 9.15 metes; this being the probable water level below which runoff apparently ceases.

Bay (1968) suggested a log-linear relationship between mean daily discharge and bog water level but the Pigeon Hill data suggest a simple mean relationship of the form:

Q_{mean} = 0.0035 x W x A .....Equation 5.1

where Q_{mean} = mean daily flow, m^3/s

W = bog water level above lowest value, m

A = drainage area, ha

Bay (1968) also discusses the seasonal trends in bog water levels which occur in northern Minnesota; trends which might also be anticipated in New Brunswick which also lies at the southern limit of the Boreal peatlands.

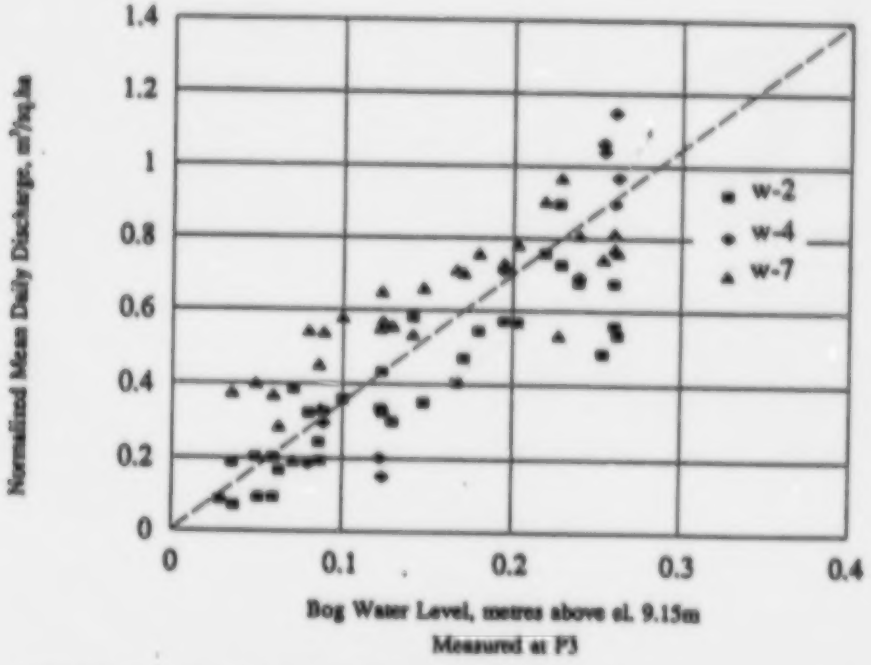


FIGURE 5.2 RELATIONSHIP BETWEEN NORMALIZED MEAN DAILY DISCHARGE AND BOG WATER TABLE ELEVATION

In Northern Minnesota, bog water levels are typically at their lowest at the end of each winter just prior to spring breakup. Once snowmelt begins and the frozen organic soil starts to thaw, the water table rises rapidly to the spring high point which is often the highest level reached during the year. After this peak, levels gradually decline except

when interrupted by precipitation events. During very dry periods, evapotranspiration and runoff result in a continuous water table recession. Water levels in the fall are usually relatively stable, depending again on the precipitation.

5.2 Hydrologic Budget

It was evident from the early stream flow data that the runoff leaving the peat bog was only a small proportion of the contributing precipitation.

An unknown but probably minor part of this difference could be attributed to evapotranspiration. Evaporation is a major factor in the summer and in the month of September, particularly in those worked areas where the farmer persistently scarifies the peat surface for the very purpose of drying it out.

Figure 5.3 shows the pan evaporation, in millimetres, for Fredericton, the closest station for which such data were available.

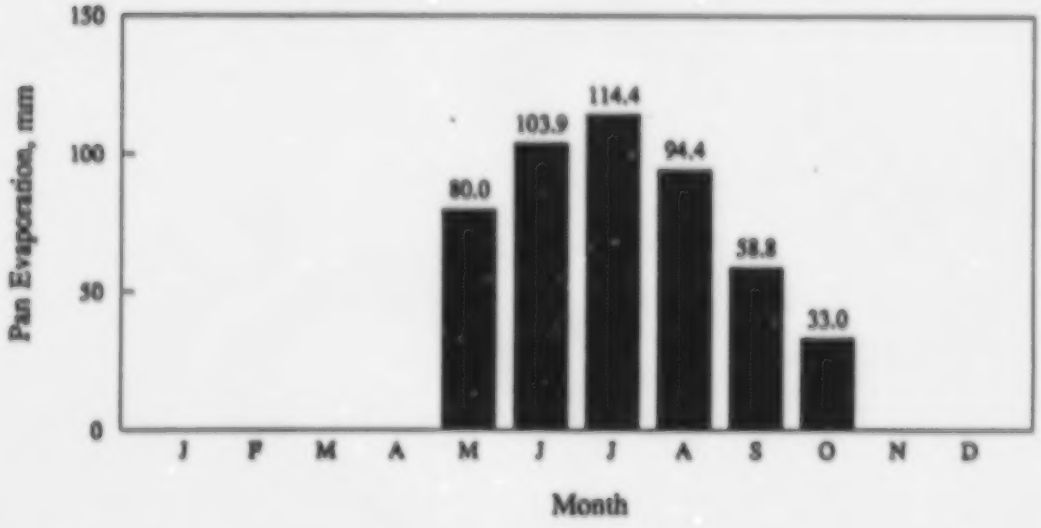


FIGURE 5.3 PAN EVAPORATION, FREDERICTON (Ref. Environment Canada, 1991)

Pan evaporation represents losses from a free water surface such as a lake. Actual evaporation losses are normally expressed as a percentage of the pan evaporation values. For groundwater levels within one metre of the surface, evaporation varies from 10 to 50 percent of pan evaporation (White, 1932).

The balance of the water budget enters storage within the peat for eventual discharge to streams via groundwater flow.

Streamflow data can be reduced to give the volume of water passing over each weir in a given period, by determining the area under each hydrograph (Figure 3.2). It is necessary, however, to know the drainage areas involved, if these flows are to be converted to an equivalent number of millimetres spread over the basin. Alternatively, such drainage areas are required for the precipitation data to be converted into equivalent discharge rates.

At the field planning stage, drainage areas were determined in a preliminary fashion from existing mapping and aerial photography. The flatness of the terrain was such, however, that the exercise proved to be unreliable based on subsequent stream flow data. The drainage area for weir W-7, for example, appeared to be considerably larger than that for W-6 but, based on the subsequent streamflow data, each proved to be of comparable size.

Given the importance of the selected drainage areas to the analysis, the originally calculated areas were adjusted using two approaches. Comparisons were first made between stream flows on an instantaneous basis; that is to say, the discharge over one weir was plotted against the discharge, at that same moment in time, over another. If the time of concentration for the compared drainage areas were the same and if the runoff characteristics were similar, then a straight-line relationship between discharges would be expected, the slope of which would be the ratio of the drainage areas.

Figure 5.4 shows instantaneous discharge data for weir W-2 plotted against that for Weir W-6. At low flows, the ratio of the discharges was approximately 2.95. At higher flows, the ratio fell to about 1.5 although since one would have expected the larger drainage area to have had the broadest hydrograph, associated with a longer time of concentration, the reverse trend might have been anticipated. It seems likely that the measured phenomenon is a real one, perhaps associated with variations in antecedent conditions. Alternatively, the large amount of storage in drainage ditches may have served to reduce peak flows at W-6. Finally, the possibility exists that Weir W-2, installed in a culvert opening, may simply have yielded inaccurate streamflow data at the higher flows.

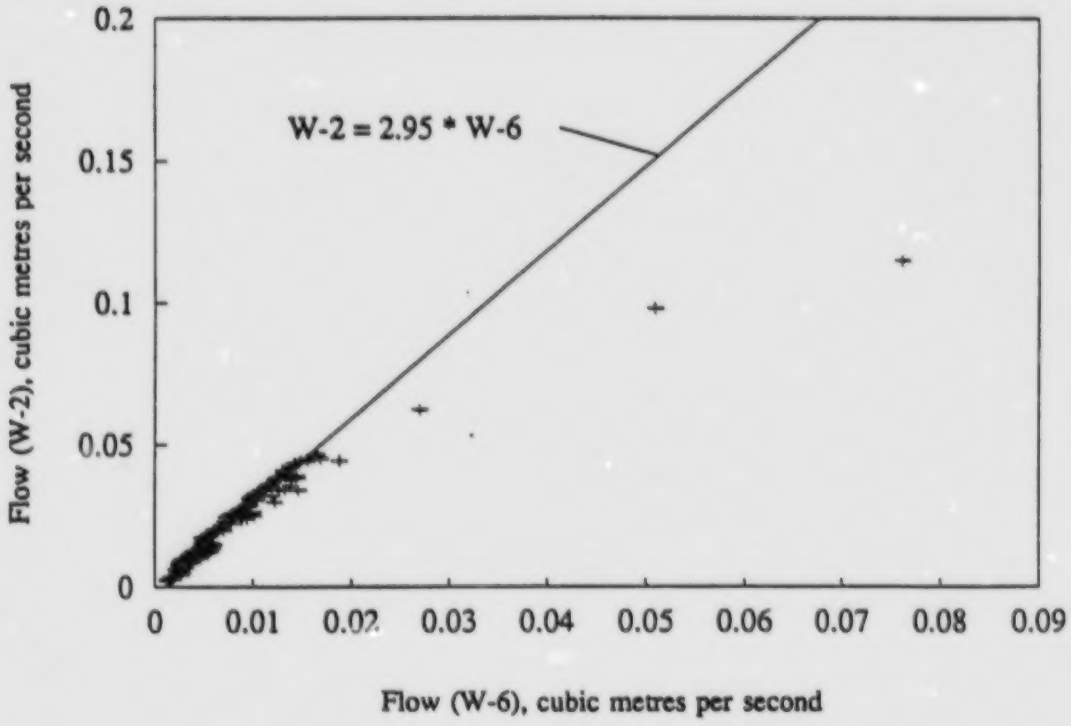


FIGURE 5.4 INSTANTANEOUS STREAM DISCHARGE W-2 VERSUS W-6

The second approach to drainage area adjustment has been to compare the total streamflow passing over various weirs in several longer periods of record for which changes in basin storage would have been relatively small.

Table 5.1 shows the total volume of water which passed weirs W-2, W-3 and W-7 in each of the three phases of the stream flow record described earlier in Section 3.2.

The ratios of total stream flow were used, together with some judgment, to arrive at the assumed drainage areas shown in Table 5.2. In the case of that area contributing to runoff to W-3, the selected area was based more on topographic considerations. Much of this drainage area is located beyond the limits of the peatland, for which runoff characteristics proved to be quite different. The assumed drainage areas are also shown in plan in Appendix D.

TABLE 5.1 TOTAL STREAM FLOWS - WEIRS W-2, W-3, AND W-7, CUBIC METRES

Time Increment	Weir W-2	Weir W-3	Weir W-7
October 7 - 23	22,000	50,300	6,900
October 23 - Nov 8	59,200	-	26,000
November 8 - 27	89,600	-	40,300
TOTAL	170,800	-	73,200

TABLE 5.2 DRAINAGE AREAS

Weir	Drainage Area, Ha	Percentage of Total Bog Area
W - 1	46.3	16
W - 2	124.4	43
W - 3	136.5	- *
W - 4	3.1	1.1
W - 5	6.9	2.4
W - 6	40.7	14
W - 7	40.7	14

* Weir W-3 receives runoff originating outside the bog.

The above difficulties with what would ordinarily be a simple task of drainage area identification and measurement, are likely to be encountered for other bogs since a lack of surface relief is likely to be typical. It may also be that the area applicable for evaluating the subsurface component of flow may be different from the "surface" drainage area, although in the above analysis, these areas are assumed to be one and the same.

The stream flows for the first period of the record given in Table 5.1 are presented in Table 5.3 together with precipitation data expressed in equivalent terms. Also shown in Table 5.1 are estimates of evapotranspiration based on Figure 5.3, and somewhat subjective baseflow estimates obtained by hydrograph separation.

Baseflow flow or dry-weather flow is the contribution of groundwater discharging into streams. It does not fluctuate rapidly because of its very low velocity through peat or organic soil. Base flows were determined by a combination of geometric and intuitive means. Base flow from one event must be adjusted by a baseflow from a succeeding event to arrive at an average. Baseflows will increase gradually over the course of an event. As more water is stored, groundwater is discharged at an increasing rate. Figure 5.5 illustrates the separation of a hydrograph into direct runoff and baseflow components.

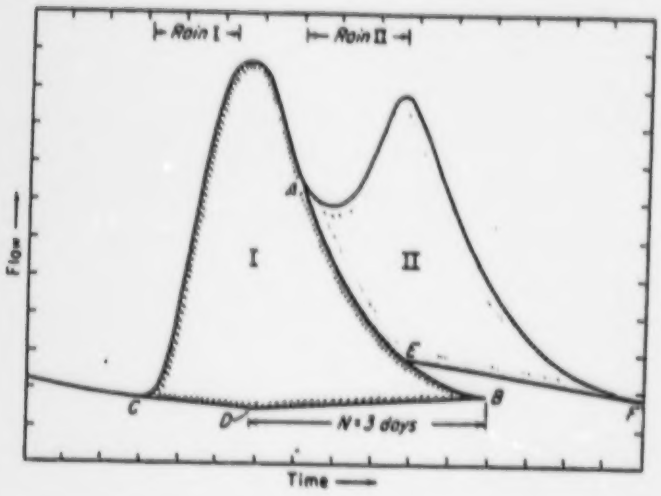


FIGURE 5.5 SEPARATION OF HYDROGRAPH USING RECESSION CURVE

(Linsley et al., 1975)

The storage terms given in Table 5.3 are the calculated values required to satisfy the water balance.

Several observations can be made concerning the water budget in this first period of field study. Firstly, recorded stream flows draining from the bog areas represented only about 22 percent of the precipitation which fell in this period. Those streams draining non-organic areas (e.g., W-3) had significantly higher flow rates, approaching 50 percent of the rainfall amount.

Although not satisfactorily confirmed by the water level data which were generally obtained at piezometers installed in actively mined areas influenced by closely spaced ditches, it appears that two thirds of the precipitation was stored in the peat for later discharge to the surface water system. The storage component was evidently less significant for those areas draining non-organic soils, for example, that area discharging to Weir W-3.

A similar approach was utilized for determining the water balance for two of the weirs for the second and third parts of the field record. The results are presented in Tables 5.4 and 5.5. Data from Tables 5.3, 5.4 and 5.5 are shown graphically in Figure 5.6.

TABLE 5.3 COMPONENTS OF THE HYDROLOGIC BUDGET
(OCTOBER 7 - 22, 1990)

COMPONENT	WEIR W-2	WEIR W-3	WEIR W-7
Area, Ha [1]	124.4	136.5	40.7
	Cubic metres (mm)	Cubic metres (mm)	Cubic metres (mm)
Precipitation (P)	100,400 (80.7)	110,200 (80.7)	32,800 (80.7)
Evaporation [2] (E)	11,200 (9.0)	12,300 (9.0)	3,700 (9.0)
Available Water (P-E)	89,200 (71.1)	97,900 (71.1)	29,100 (71.1)
Overland Flow (S-G)	14,000 (1.3)	41,000 (30.0)	4,000 (3.8)
Groundwater Interflow to Stream (G)	8,000 (6.4)	9,300 (6.8)	2,900 (7.1)
Storage (P-E) - S	67,200 (54.0)	47,600 (34.9)	22,200 (54.5)
Streamflow (S)	22,000 [3] (17.7)	50,300 [3] (36.8)	6900 [3] (16.9)

Notes
[1] From Table 5.2
[2] Evapotranspiration assumed to be 50 percent of the pan evaporation from Figure 5.2 [i.e., 0.5 x (17 days ÷ 31) x 33 mm = 9.0 mm]
[3] From Table 5.1

TABLE 5.4 COMPONENTS OF THE HYDROLOGIC BUDGET

OCTOBER 23 - NOVEMBER 8, 1990)

COMPONENT	WEIR W-2	WEIR W-7
Area, Ha [1]	124.4	40.7
	Cubic metres (mm)	Cubic metres (mm)
Precipitation (P)	115,700 (93.0)	37,900 (93.0)
Evaporation [2] (E)	-	-
Available Water (P-E)	115,700 (80.6)	37,900 (93.0)
Overland Flow (S-G)	44,300 (35.6)	20,100 (49.4)
Groundwater Interflow to Stream (G)	14,900 (12.0)	5,900 (14.5)
Storage (P-E) - S	56,500 (45.4	19,000 (29.2)
Streamflow (S)	59,200 [3] (46.7)	26,000[3] (63.9)

Notes

[1] From Table 5.2

[2] Evapotranspiration assumed to be 50 percent of the pan evaporation from Figure 5.2 [i.e., 0.5 x (17 days + 31) x 33 mm = 9.0 mm]

[3] From Table 5.1

TABLE 5.5 COMPONENTS OF THE HYDROLOGIC BUDGET
(NOVEMBER 9 - NOVEMBER 27, 1990)

COMPONENT	WEIR W-2	WEIR W-7
Area, Ha [1]	124.4	40.7
	Cubic metres (mm)	Cubic metres (mm)
Precipitation (P)	100,300 (80.6)	32,800 (80.6)
Evaporation [2] (E)	-	-
Available Water (P-E)	100,300 (80.6)	32,800 (80.6)
Overland Flow (S-G)	53,600 (43.1)	19,500 (47.9)
Groundwater Interflow to Stream (G)	36,000 (28.9)	20,800 (51.1)
Storage (P-E) - S	10,700 (8.6)	-7,500 (-18.4)
Streamflow (S)	89,600 [3] (72.0)	40,300 [3] (99.0)

Notes
[1] From Table 5.2
[2] Evapotranspiration assumed to be 50 percent of the pan evaporation from Figure 5.2 [i.e., 0.5 x (17 days ÷ 31) x 33 mm = 9.0 mm]
[3] From Table 5.1

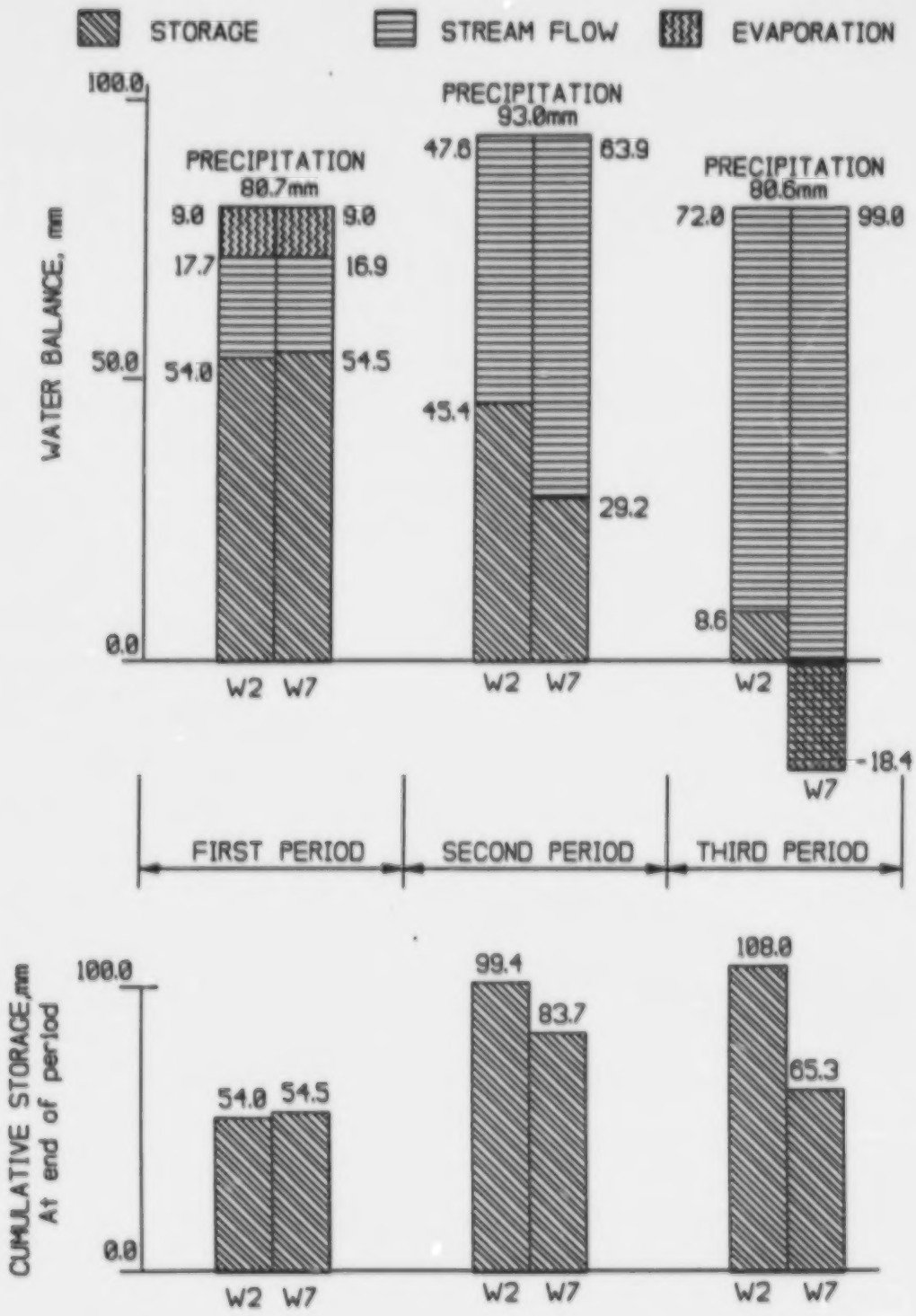


FIGURE 5.6 WATER BALANCE AT WEIRS W-2 AND W-7 FOR EACH PERIOD OF RECORD

Although the total precipitation occurring in the first and third periods of the field record were similar, the base streamflows were higher by a factor of at least four towards the end of the wet season when losses to storage diminished and in the case of the area contributing to flow at W-7, a significant amount of water drained out of storage.

At the beginning of the study period the bog was relatively dry, the water table being low, and storage space available. At the end of the study period antecedent conditions were wet and most of the bog storage area was occupied. Therefore most precipitation was discharged as direct runoff, as there was little or no storage space available.

Figure 5.7 shows various components of the hydrologic budget, as might apply on a monthly basis at Pigeon Hill. Rainfall and snowfall amounts are simply those for the City of Bathurst (Figure 3.4) increased by 11 percent - the amount by which the total precipitation on Lameque exceeds that at Bathurst (DMAE, 1987). Snowmelt was estimated by applying monthly Melt factors to the snowfall. The factors were adjusted until the snow on the Ground at the end of March was comparable with the documented average water content of snowpack at that time (DMAE, 1987). Evapotranspiration is known to be relatively high in areas where water is freely available (Freeze and Cherry, 1979). Evapotranspiration was therefore arbitrarily assumed to be one-half of the pan evaporation at Fredericton shown in Figure 5.3; fifty percent being at the high end of the range noted by White (1932).

From Figure 5.7 it is evident that although the amount of water available for runoff is fairly high in the fall of each year, it may only be one half of that available in the spring.

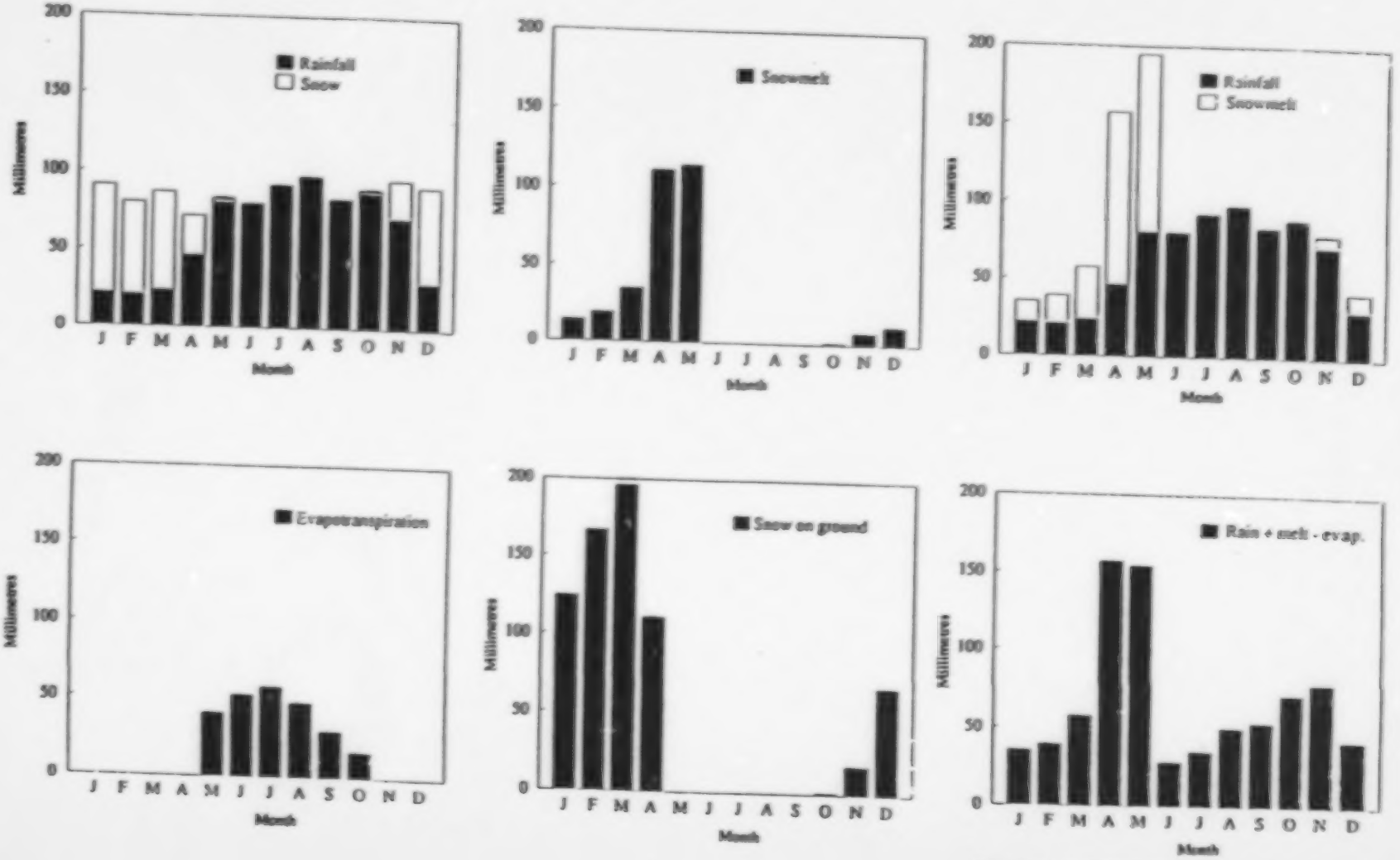


FIGURE 5.7 MONTHLY HYDROLOGIC BUDGET
PIGEON HILL N.B.

5.3 Peak Flow Analysis

A number of methods are available for estimating the amount of runoff from a drainage area. For small catchment areas, the Rational Method is the one most widely used in the design of drainage structures. It is based on the following empirical rainfall intensity runoff relationship:

$Q = C\,I\,A$ Where Q = runoff (in m^3/s).....Equation 5.2

C = runoff coefficient

I = rainfall intensity (m/s)

and A = Area (m^2)

The appropriate rainfall intensity to be used in Equation 5.2 is the average intensity occurring within the time of concentration, T_c. The time of concentration is the time it takes for drop of water to move from the furthest point in the drainage area to the point at which the discharge is to be predicted.

T_c can be estimated empirically based on the drainage basin geometry and surface slope. One such equation, developed by Kirpich (1940) is as follows:

$$T_c = 0.000325 \frac{L^{0.77}}{S^{0.385}} \quad \text{.....Equation 5.3}$$

Where T_c is the time of concentration in hours

L is the maximum length of travel of water, m

and S is the slope, equal to H/L where H is the difference in elevation between the most remote point in the basin and the outlet.

Although the travel length, L, can be estimated reasonably well once the basin area has been identified, the slope, S, is more difficult to determine without field surveying, because of the overall flatness of a typical peatland drainage area. Nevertheless, Equation 5.3 might be applied to the drainage area contributing runoff to Weir 2 as follows:

$$T_c = 0.000325 \frac{L^{0.77}}{S^{0.385}}$$

T_c = 1.28 hours for L = 2000 m and S = 0.00175

When stream hydrograph data are available, the time of concentration can be determined graphically as the time interval between onset of rain and the time of peak streamflow. Typical T_c values for Weir W-2 determined in this manner varied from .5 to 2 hours.

As discussed in Section 5.2, the flat nature of the terrain made it difficult to accurately determine the drainage areas contributing runoff to specific ditches or streams. The applicable areas for the installed weirs were tabulated earlier (Table 5.2).

The runoff coefficient, C, varies with surface conditions and soil type, and with antecedent precipitation conditions. Values of C vary from practically zero for very flat surfaces where the soil is pervious to in excess of 0.7 for concrete or asphalt surfaces, as shown in Table 5.6 (A.I.S.I., 1984).

TABLE 5.6 RUNOFF COEFFICIENTS (AISI, 1984)

Type of Surface	Runoff Coefficient
Asphalt Pavement	0.80 - 0.95
Concrete Pavement	0.70 - 0.90
Gravel Pavement	0.35 - 0.70
*"Impervious" soils	0.40 - 0.65
*"Slightly pervious" soils	0.15 - 0.40
*"Moderately pervious" soils	0.05 - 0.20

* Slopes at 1 to 2%

Runoff coefficients would typically be reduced by 0.01 where soils are covered with an organic mat of turf.

Peak stream flows at Weirs W-2 and W-7 are plotted against the appropriate products of rainfall intensity (m/s) and basin area (m^2) in Figure 5.8. If the runoff characteristics of each drainage area remained constant throughout the period of field study, the data points would fall on a straight line; the slope of which would be the runoff coefficient.

The poor relationship between Q and IA evident from Figure 5.8 occurs because of variations in runoff which occur because of variable antecedent precipitation conditions.

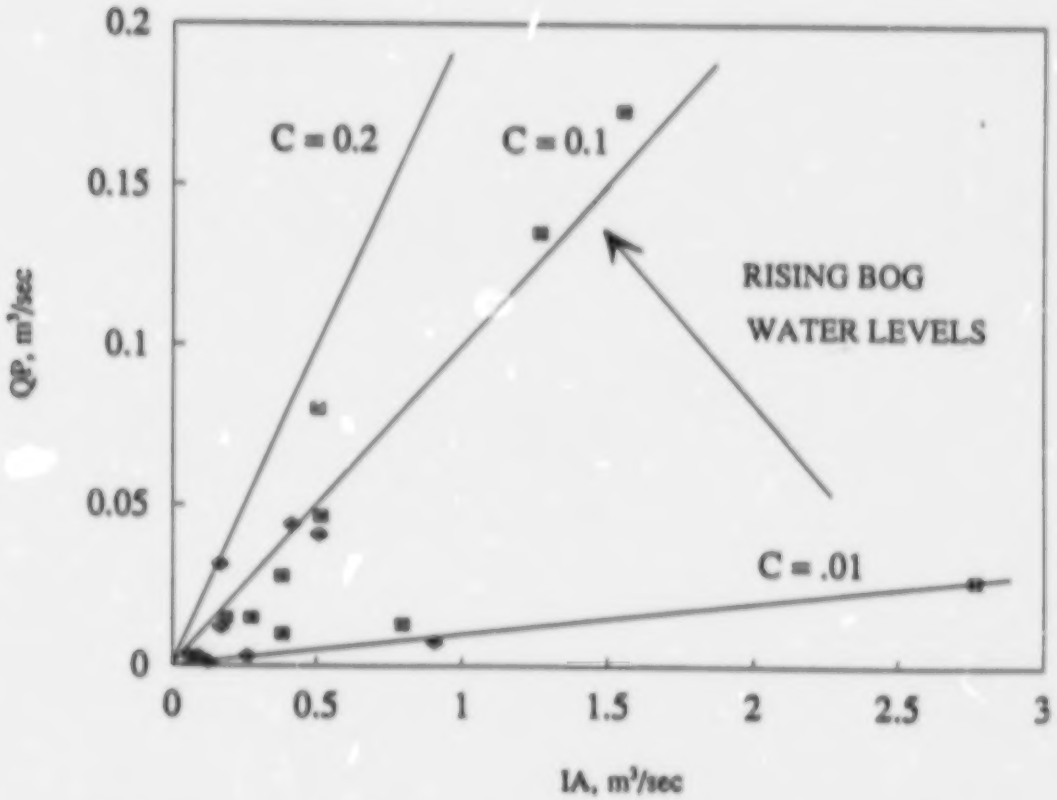


FIGURE 5.8 PEAK STREAM FLOW (Qp) VERSUS IA, WEIRS W-2 AND W-7

The importance of antecedent precipitation conditions on infiltration and therefore on runoff characteristics is well known and has been demonstrated in this study both in the field and laboratory. In the field, two early rainfall events produced significant runoff above base flow. Events A-1 and A-2 were similar in intensity and duration but resulted in very different stream flows at the monitored weirs. Table 5.7 shows that the second event, which occurred when the water level in the peat was somewhat higher, produced nearly double the runoff than did the first. It was demonstrated earlier (Figure 5.2 and Equation 5.1) that mean daily flows were directly proportional to the bog water level, measured above its lowest value.

TABLE 5.7 DETAILS OF SELECTED RAINFALL EVENTS

Rainfall Event	Rainfall Intensity mm/hr	Rainfall Duration hrs	Equivalent runoff mm	Implied Infiltration mm	Implied Infiltration rate, mm/hr
A1	1.11	13.2	1.10	13.3	1.01
A2	0.79	17.9	1.70	12.5	0.70
A	0.53	54.0	2.80	25.8	0.48
B1	2.30	1.9	0.80	3.6	1.90
B2	8.00	0.8	0.78	5.6	7.00
B	1.49	28.7	14.10	28.6	1.00
C	4.49	18.9	69.4	15.4	0.82
D	1.10	2.9	0.50	2.7	0.93
E	3.66	7.9	28.90	0.0	0.00
F	1.46	18.5	14.40	12.6	0.68

In the laboratory, discharge characteristics only stabilized after the columns of peat had been repeatedly soaked.

A variety of modifications to the rational method have been proposed to take into account antecedent precipitation conditions (AISI, 1984). The approach utilized here is to replace

the runoff coefficient C with three factors, C_1, C_2, and C_3; each one varying from 0 to 1. The peak flow Q_{peak} is then estimated from Equation 5.4 as follows:

$$Q_{peak} = C_1 \cdot C_2 \cdot C_3 \cdot IA \qquad \text{.....Equation 5.4}$$

where C_1 = water level factor

C_2 = rainfall factor

and C_3 = surface condition factor.

The water level factor, C_1, takes into account antecedent precipitation conditions. Since peak flows are likely to be greater than mean daily discharges by a constant factor (DMAE, 1987), and since the mean daily discharge proved to be directly proportional to the bog water level above its lower value, then C_1 might also be expected to vary in a linear manner with water level. It is proposed that C_1 equals 0.05 when bog water levels are at their lowest; 1.0 when they are at their highest, and 0.5 when they are at intermediate levels.

A rainfall factor, C_2, is necessary because runoff increases as rainfall intensity approaches and exceeds the rate at which infiltration into the soil can occur. It is proposed that a minimum C_2 value of 0.5 be considered for low intensity rains; 1.0 for high intensity storms, and 0.75 for those of intermediate magnitude.

Finally, surface conditions are taken into account by the factor C_3 for which a value of 0.5 is proposed for the Pigeon Hill peatland. C_3 would presumably increase in those peatland areas where the surfaces slopes were steeper or where developed land formed a greater proportion of the whole. Conversely, C_3 would be less then 0.5 in an even flatter area, or in one where a lower percentage of the land was developed. More work would be required to refine these surface condition factors.

The revised runoff coefficient (C_1 x C_2 x C_3) as defined above would approach zero in those instances where light rainfall followed a long drying period when bog water levels

were low. In practice, the streamflow in such a situation would never be zero because of channel precipitation. Highest runoff would occur with intense rainfall over previously saturated ground; the maximum runoff coefficient ($C_1 \times C_2 \times C_3$) being 0.5 for Pigeon Hill, controlled by surface conditions. During the study period, the maximum value for $C_1 \times C_2 \times C_3$ was 0.16. In Figure 5.9, peak flows calculated by Equation 5.4 are plotted against actual peak flows.

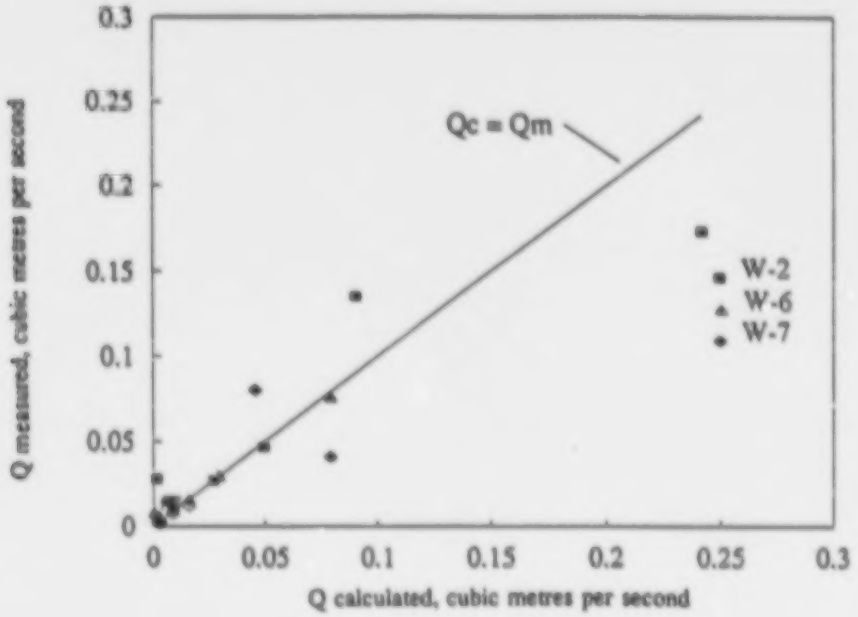


FIGURE 5.9 CALCULATED VERSUS MEASURED PEAK STREAM FLOWS

5.4 Relationship between Stream Discharge and Water Quality

5.4.1 Suspended Solids

A variety of mechanisms exist whereby peat fibres can enter the water stream. These include the airborne transport of fibres onto the surface of water in ditches, and the erosion of such ditches by the passage of water and/or by farming activity. Farming activity is particularly important because scarification of the fields results in generation of more wind blown fibres and because ditch construction or maintenance can release

short duration slugs of high-suspended-solids water. Ditch maintenance was most probably responsible for unusual fluctuations in weir flow, particularly at W-7, on a few occasions.

Since ditch erosion is exacerbated at times of high flow (Gregory, et al., 1984), the relationship between suspended solids and flow rates has therefore been examined. Figure 5.10 shows all suspended solids data plotted against the corresponding weir flow. The relationship between the two parameters is somewhat tenuous, but several conclusions can be drawn. Suspended solids were generally highest at those weirs located closest to actively operated fields (W-1, W-4, and W-5), and were an order of magnitude lower at the down gradient outlet of the basin. The implication is that peat fibres are settling out in the drainage ditches.

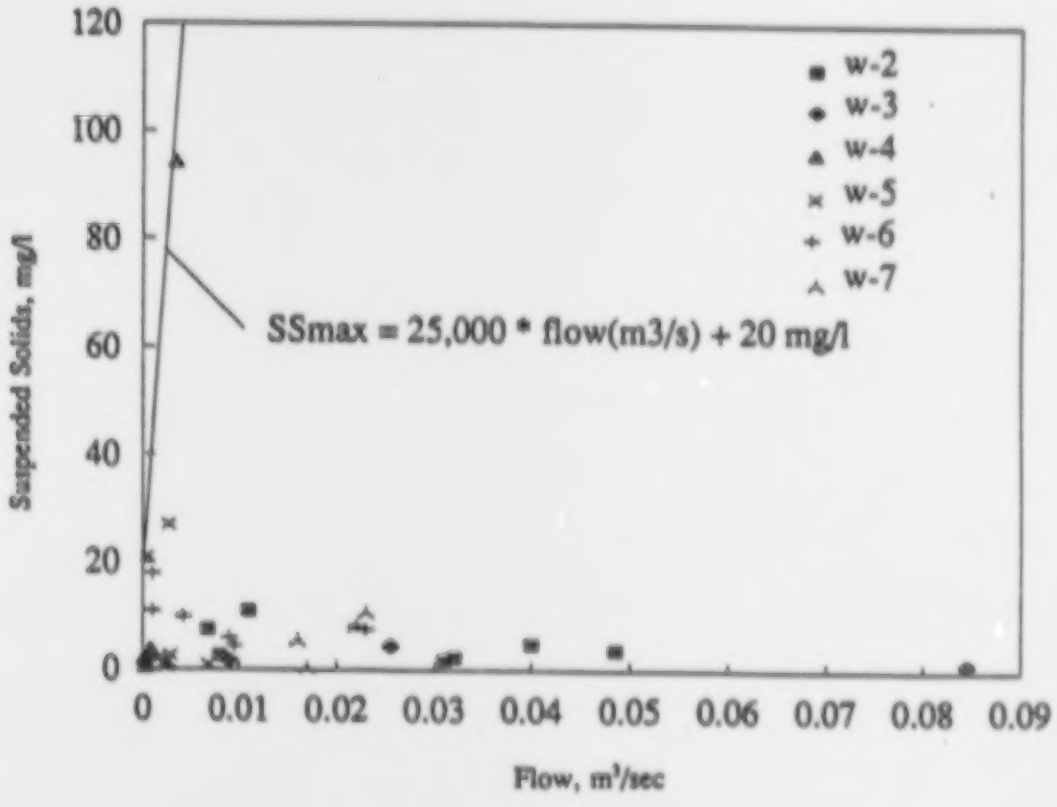


FIGURE 5-10 SUSPENDED SOLIDS (mg/l) VERSUS FLOW

Suspended solids never exceeded SS_{MAX} where:

SS_{MAX} = 25000 x (flow in cubic metres per second) + 20 mg/l.....Equation 5.4

Away from the actively mined area, suspended solids were generally less than 15 mg/l, irrespective of flow conditions.

The suspended solids data are plotted versus flow on a Kg per day basis in Figure 5.11.

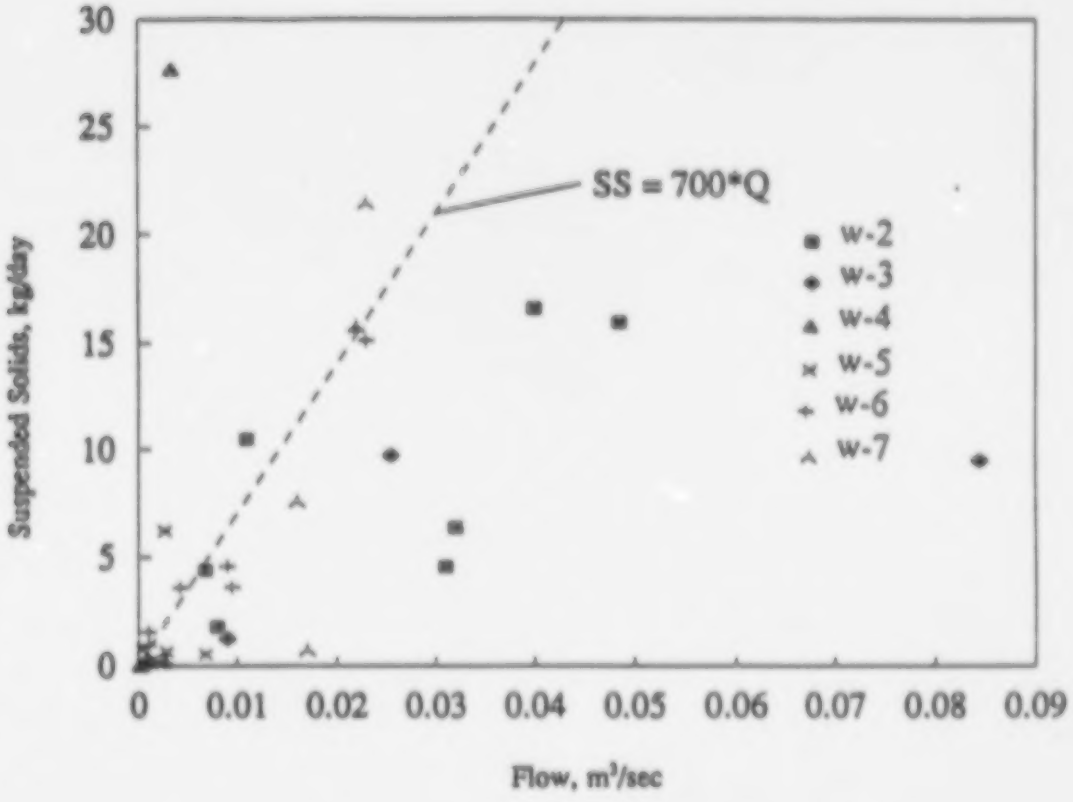


FIGURE 5-11 SUSPENDED SOLIDS (kg/day) VERSUS FLOW

In this form, it is apparent that the total transported solids do increase with flow rate, with equivalent dry weights of transported peat approaching 30 Kg per day.

The weight of transported fibres is approximated by Equation 5.5

$$SS_{per\ day} = 700 \times Q \quad \text{.....Equation 5.5}$$

where $SS_{per\ day}$ = Suspended Solids, Kg per day by dry weight

Q = instantaneous flow, m^3/s

The suspended solids concentration implied by Equation 5.5 is 8 mg/l.

Neither of the above relationships should be applied to other situations, however, without consideration of more data than evaluated in this study.

An estimate of the total suspended solids load discharged at Weir W-2 in the period October 7 to November 27, 1990 can be made as follows:

Suspended solids load = 4.8 [1] mg/l x 170,800 [2] [cubic metres] x 1000 [litres]

= 820 Kg (dry measure)

Notes: [1] From Table 3.2

[2] From Table 5.1

The corresponding suspended solids load for Weirs W-5, W-6 and W-7 would have been 114, 680 and 285 Kg, respectively, in this period. Figure 5.12 shows these suspended solid values diagrammatically.

Somewhat higher sediment loads would be obtained using Equation 5.5, since that relationship is based on the high TSS of 8 mg/l.

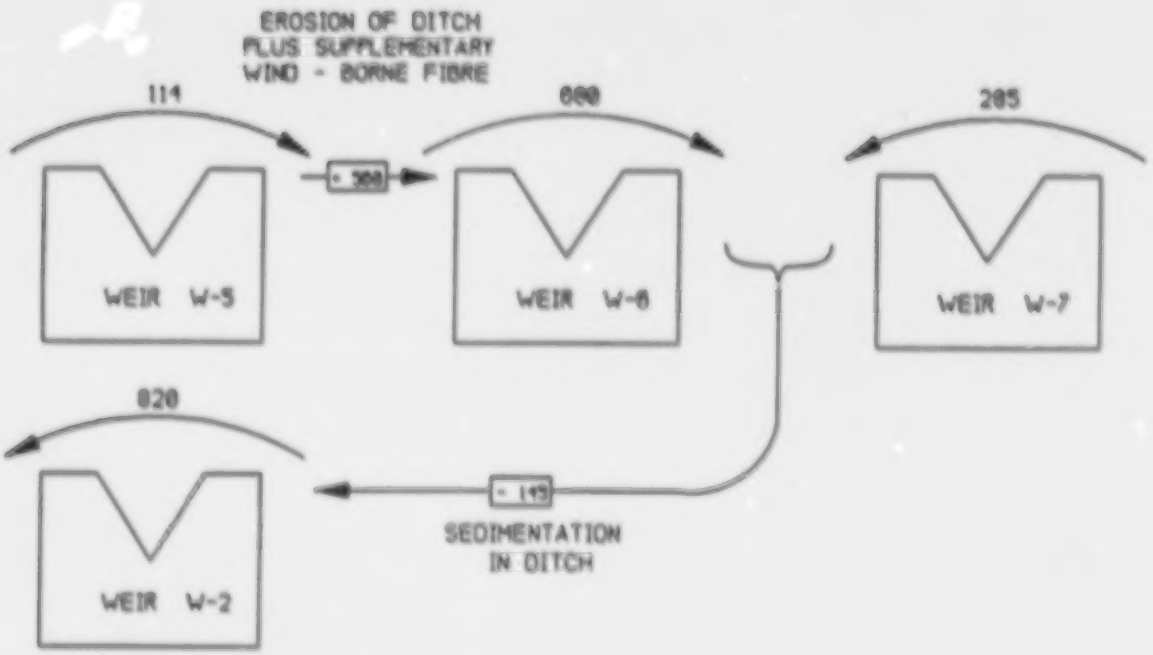


FIGURE 5-12 CALCULATED SEDIMENT TRANSPORT, Kg OCTOBER 7 TO NOVEMBER 27, 1990

The suspended solid load at Weir W-6 is substantially higher than that at the upstream Weir W-5, suggesting that erosion of and/or collection of supplementary wind-borne fibres has occurred in the intervening ditch. Sedimentation appears to be occurring, however, between Weirs W-6 and W-7, and Weir W-2, based on the above approach.

The total dry weight of transported suspended solids appeared to be relatively low in the period of field record. The equivalent volume of fibre transported in this period to Weir W-2, expressed in a settled-out condition, would be 9 to 22 cubic metres, based on an assumed fibre specific gravity of 1.4 (Radforth, et al., 1977) and on assumed moisture contents of 1000 to 3000 percent, respectively (Figure 4.2).

5.4.2 Acidity

Values of pH from Table 3.3 are plotted in Figure 5.13. Although pH fluctuations at individual stations did occur with time, the fluctuations were generally less significant than were the differences in pH observed between the different sampling points. At Weirs W-1, W-4, W-5 and W-7, located within or very close to the actively farmed area, surface water pH varied from 4 to 5, in each case rising slightly towards the end of the observation period, when flows were at their greatest. The relatively low pH in these surface waters is a reflection of the intimate contact between the overland and groundwater components with low pH organic soil.

The surface water pH measured at Weir W-3 was considerably higher than that determined at locations near the mined fields. The pH value at Weir W-3 remained remarkably constant at a little under six over the period of observation, suggesting that only a small proportion of the runoff had been in close contact with the peat.

More difficult to explain is the fact that the highest recorded pH values, approaching 6.5, occurred at Weir W-6. The relatively low pH water from the upstream weir may be diluted by less acid water discharging into the intervening ditch via the zone of mineral soil. The mineral soil is apparently recharged from the lake to the north - a conclusion also reached from water-balance considerations. Recharge would occur through the 0.3 - 0.6 m thick silty sand layer which underlies the peat, which in turn is above the glacial till.

One cannot utilize the pH data alone, however, to reliably estimate the sources or chemistries of various components of the streamflow.

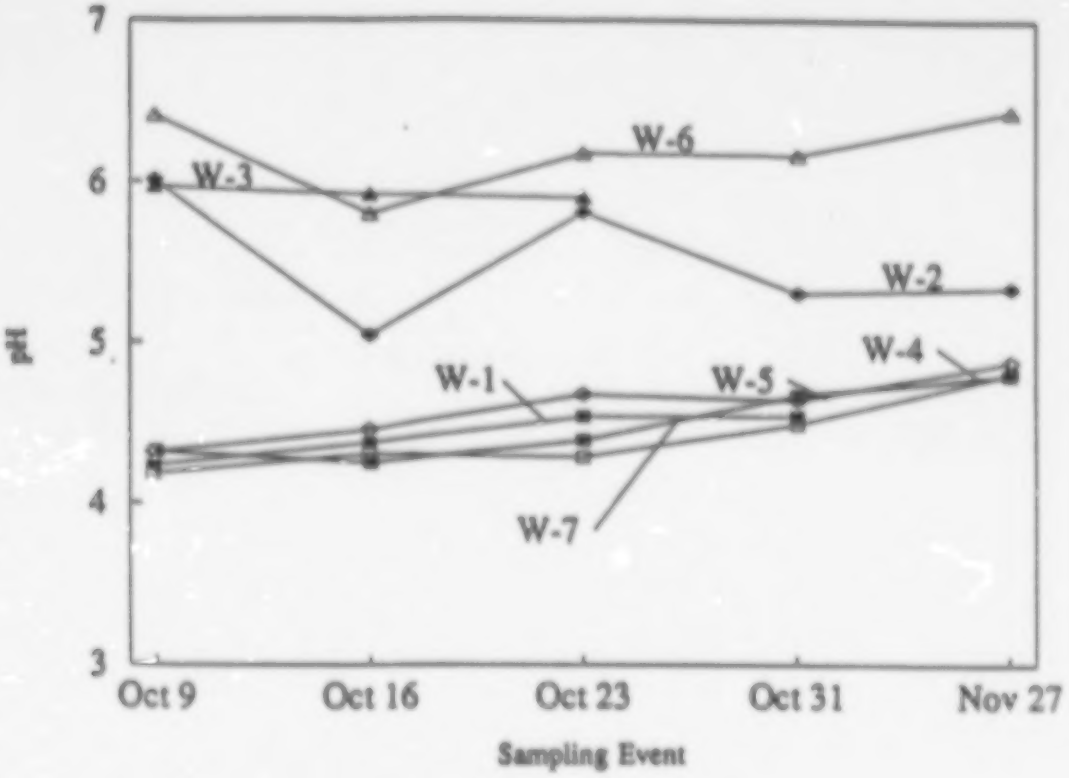


FIGURE 5-13 SURFACE WATER pH AT VARIOUS LOCATIONS FOR FIVE SAMPLING EVENTS

6.0 DESIGN PARAMETERS

Sedimentation ponds for a peatland such as this are customarily designed so as to reduce suspended solids concentrations to an acceptable level prior to discharge to receiving waters. An appropriate pond would be one sized large enough to permit adequate retention or settling time, and also large enough such that cleaning out need only be necessary at reasonable intervals. Hammon and Coffey (1984) report that significant settling out of peat solids from suspension occurs only when the horizontal flow velocity is less than 0.15 m/s. They observed that settling times in excess of 11 hours resulted in adequate solids retention, and reasoned that a pond length of 100 metres would be required.

Settling time might be estimated directly from Stoke's Law as follows:

$$\text{Settling time, } t_s = \frac{\text{pond depth } z}{\text{settling velocity, } V_s} \quad \text{.....Equation 7.1}$$

$$\text{Where } V_s = \frac{g \cdot d^2 (p - \sigma)}{18 \cdot 2 \cdot \eta} \quad \text{.....Equation 7.2}$$

and where
- g = acceleration due to gravity
- d = "fibre diameter"
- p = fibre density
- σ = water density
- η = dynamic viscosity of water

Table 6.1 shows theoretical settling velocities and times for the fibre sizes obtained on dry sieving the Pigeon Hill sphagnum.

TABLE 6.1 THEORETICAL SETTLING VELOCITIES AND TIMES FOR VARIOUS FIBRE SIZES

Mesh Size mm	Settling Velocity, Vs m/s			Time to Settle 1 metre, hours		
	G_{Fibre} 1.02	G_{Fibre} 1.20	G_{Fibre} 1.40	G_{Fibre} 1.02	G_{Fibre} 1.20	G_{Fibre} 1.40
5	2.7×10^{-3}	2.7×10^{-2}	5.5×10^{-2}	0.1	0.01	0.005
2.5	6.8×10^{-4}	6.8×10^{-3}	1.4×10^{-2}	0.4	0.04	0.02
0.63	4.3×10^{-5}	4.3×10^{-4}	8.7×10^{-4}	6.4	0.6	0.3
0.315	1.1×10^{-5}	1.1×10^{-4}	2.2×10^{-4}	26	2.6	1.3
0.160	2.8×10^{-6}	2.8×10^{-5}	5.6×10^{-5}	100	10	5
0.080	7.0×10^{-7}	7.0×10^{-6}	1.4×10^{-5}	400	40	20

From Table 6.1 it is apparent that settling velocities and times are particularly sensitive to peat fibre specific gravity. Hammon and Coffey (1984) report peat specific gravities to be in the range of 1.02 to 1.04, although higher values are documented elsewhere (Walmsley, in Radforth, et al., 1977), and implied from laboratory testing carried out as part of this study. Settling times decrease by a factor of 20 as the specific gravity increases from 1.02 to 1.40.

In the laboratory settling tests, much of the fibre was still floating on the water surface after 24 hours; therefore having an apparent specific gravity of less than one. Those particles that did settle, however, had substantially done so after two or three hours, suggesting settling velocities as high as 1×10^{-5} m/s.

When the settling characteristics of the peat fibres are better understood, the time required for proper sedimentation can be refined. The sedimentation ponds must also be long enough or at least have a sufficient retention time such that individual fibres can settle out from the top to bottom of the water column before reaching the outlet of the structure. For a given volume, long ponds would be favoured over square ones because they could be cleaned out more readily using conventional excavation equipment.

It became evident during lab experimentation that peat particles settled faster once they were wetted. Even after wetting, most of the larger particles floated. Therefore it may be useful to include mechanisms in the settling pond to encourage settling out of solids. An apparatus capable of creating turbulence, thereby wetting the floating particles, might be placed at the entrance of the pond; a simple weir would probably suffice. A "skimming" apparatus might alternatively be placed at the outlet of the settling pond to remove floating particles from the surface.

Preliminary sedimentation pond design might be made using the following approach. Several of the assumptions made here were discussed in earlier sections.

1. Determine the average stream flow, $Q_{average}$

   Say drainage area = 50 hectares

   Use Q = 0.00025 m^3/s per hectare

   therefore Q = 0.0125 m^3/s

2. Determine average sediment load

   Say TSS = 40 mg/l from year round field measurement

   Sediment load = 0.0125 [m^3/s] x 40 [mg/l]

   = 0.0125 [m^3/s] x 40 x 10^{-3} [Kg/m^3]

   = 5 x 10^{-4} [Kg/s]

3. Determine required pond volume, V_1, for a reasonable clean-out interval.

$$V_1 = \frac{\text{Clean out interval [s]} \times 5 \times 10^{-4}\ [\text{Kg/s}]}{\text{Density of settled solids, } \rho_s\ [\text{Kg/m}^3]}$$

Say clean out interval = 6 months = 1.58×10^7 [s]

and ρ_s = 40 [Kg/m^3]

then $V_1 = \frac{1.58 \times 10^7\ [\text{s}] \times 5 \times 10^{-4}\ [\text{Kg/s}]}{40\ [\text{Kg/m}^3]}$ = 197.5 m^3, say 200 m^3

4. Estimate settling time based on field or laboratory test, for pond depth.

$$\text{Settling time} = \frac{\text{Pond depth}}{\text{Settling velocity, } V_s} = \frac{2\ [\text{m}]}{2 \times 10^{-4}\ [\text{m/s}]}$$

= 10,000 seconds

= 2.8 hours

5. Determine probable peak flow using hydrograph data or one or more of the following empirical equations:

a) $Q_{peak} = C_1 \cdot C_2 \cdot C_3 \cdot I \cdot A$ as described in Section 5

b) $Q_{peak} = 4 \times Q_{average}$

$= 4 \times 0.0125\ [\text{m}^3/\text{s}]$

$= 0.05\ [\text{m}^3/\text{s}]$

6. Determine required pond volume for the calculated retention time.

$V_2 = Q_{peak} \times$ settling time

$= 0.05\ [\text{m}^3/\text{s}] \times 10{,}000\ [\text{s}]$

$= 500\ \text{m}^3$

Use $V = V_1 + V_2 = 700\ \text{m}^3$

7. Select pond length, L.

$$L = \frac{\text{volume}}{\text{width} \times \text{useful depth}}$$

$$= \frac{700\ [\text{m}^3]}{5\ [\text{m}] \times 2\ [\text{m}]} = 70\ \text{metres}$$

In practice, the above approach should be tested by field trial. A simple pond should be constructed and then monitored, preferably over one full year. Monitoring should comprise periodic determination of influent and effluent total suspended solids, the flow rates and the accumulated sludge volume.

7. CONCLUSIONS

1. The field study period, which included late September, October and November 1990, was an exceptionally wet one with precipitation exceeding mean monthly values by nearly 50 percent.

2. Recorded peak stream flows in this period were typically 0.001 to 0.002 m^3/s per hectare of drainage area while the average flow rates were in the range 0.00025 to 0.00050 m^3/s per hectare. The 0.00025 m^3/s per hectare rate is probably a reasonable value to use as a year round average; this being equivalent to a net precipitation of approximately 750 mm.

3. Peak flows were significantly lower than those documented for non-peatland areas. A substantial part of the new rainfall percolated downwards to groundwater storage from where it was later released slowly. An estimated forty percent of the precipitation which fell within the catchment of Weir W-2, for example, remained in storage at the end of November.

4. Mean daily runoff values are roughly proportional to bog water levels.

5. Runoff characteristics vary significantly with rainfall intensity and with antecedent precipitation conditions; these latter being manifested by fluctuations in bog groundwater levels of about 30 centimetres. At low bog water levels, runoff is minimal. Peak flows might be crudely estimated from the expression:

$$Q_{peak} = C_1 \cdot C_2 \cdot C_3 \cdot I \cdot A$$

Where C_1 is a water level factor depending on the bog water level; C_2 and C_3 are rainfall and surface condition factors, respectively, and where I and A are the rainfall intensity and drainage areas, respectively; all in compatible units. During the study period the

value for C_1 ranged from 0.5 to 1.00, C_2 ranged from .05 to 0.95, while C_3 was 0.5. The combined value, $C = C_1 \cdot C_2 \cdot C_3$, ranged from 0.02 - 0.16.

6. Measured suspended solids were generally low in the study period with only two test results exceeding 50 mg/l. Suspended solids were generally highest at those weirs located closest to actively farmed fields. Ditch maintenance activity and the airborne transport of peat fibres have a greater effect on the sediment load than the erosion of ditches by passage of water. On the contrary, appropriately sized ditches will serve as sedimentation ponds. The expression:

$$SS_d = 700 \cdot Q$$

where SS_d is the suspended solids in kG per day and where Q is the instantaneous flow in cubic metres per second, gives a suggested upper limit to the daily transported load, at least as observed in the period of field record. The implied total suspended solids value is 8 mg/l. The maximum measured suspended solids levels during the study can be defined by the expression 20 mg/l + 25000 Q.

7. Settling characteristics are particularly sensitive to peat specific gravity which can evidently vary from less than one for floating fibres, to 1.4 or 1.5. Settling ponds must be large enough to accommodate silt build-up without necessity for frequent cleaning out, and with a large enough retention time so as to permit adequate settling out of peat solids.

8. Although there is a 2-metre separation between the perched bog and bedrock water table there is essentially no hydraulic connection. The perched water table in the bog contributes a negligible amount of water to the bedrock water system. The low recharge rate from perched water in the bog is due to low permeability of the peat and underlying glacial till. The bedrock water system is recharged upgradient of peat area and is essentially independent of the peat bog.

8. RECOMMENDATIONS

1. Although the field work for this project was carried out during a relatively wet fall, it is evident from analysis of the hydrologic budget that far larger streamflows will occur in the spring. Accordingly, it is recommended that additional elements of the field work be carried out during spring runoff. These would include additional runoff, groundwater level and water chemistry measurements.

2. Review other peat bog operations for suitable locations to measure runoff with which to test further the models developed during this study.

3. Carry out further evaluation of suspended solids discharge from operating bogs by periodic volumetric measurements of solids trapped in existing sedimentation ponds. Correlate with runoff where possible. Check solids levels in both influent and effluent to evaluate settling efficiency.

4. Conduct additional lab and field tests on peat solids collected in existing settling ponds to evaluate the settling characteristics. Conduct visual surveys to evaluate the amount of material actually carried by floating on ditch water surfaces.

5. Evaluate through field measurements the effects of ditch construction and clensing on suspended solids carried in the runoff.

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C. G. KEATS, E.I.T., B. Sc.

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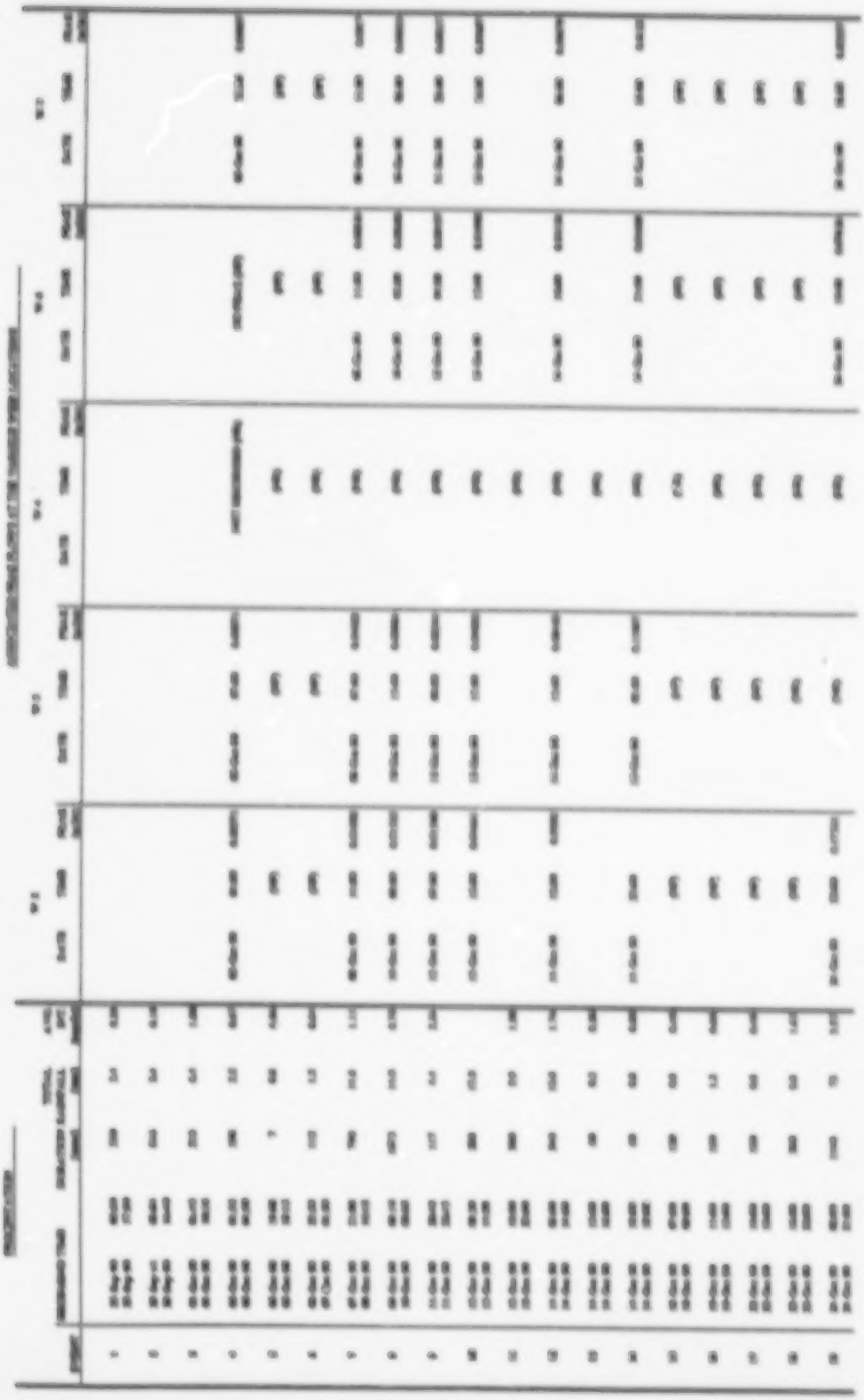
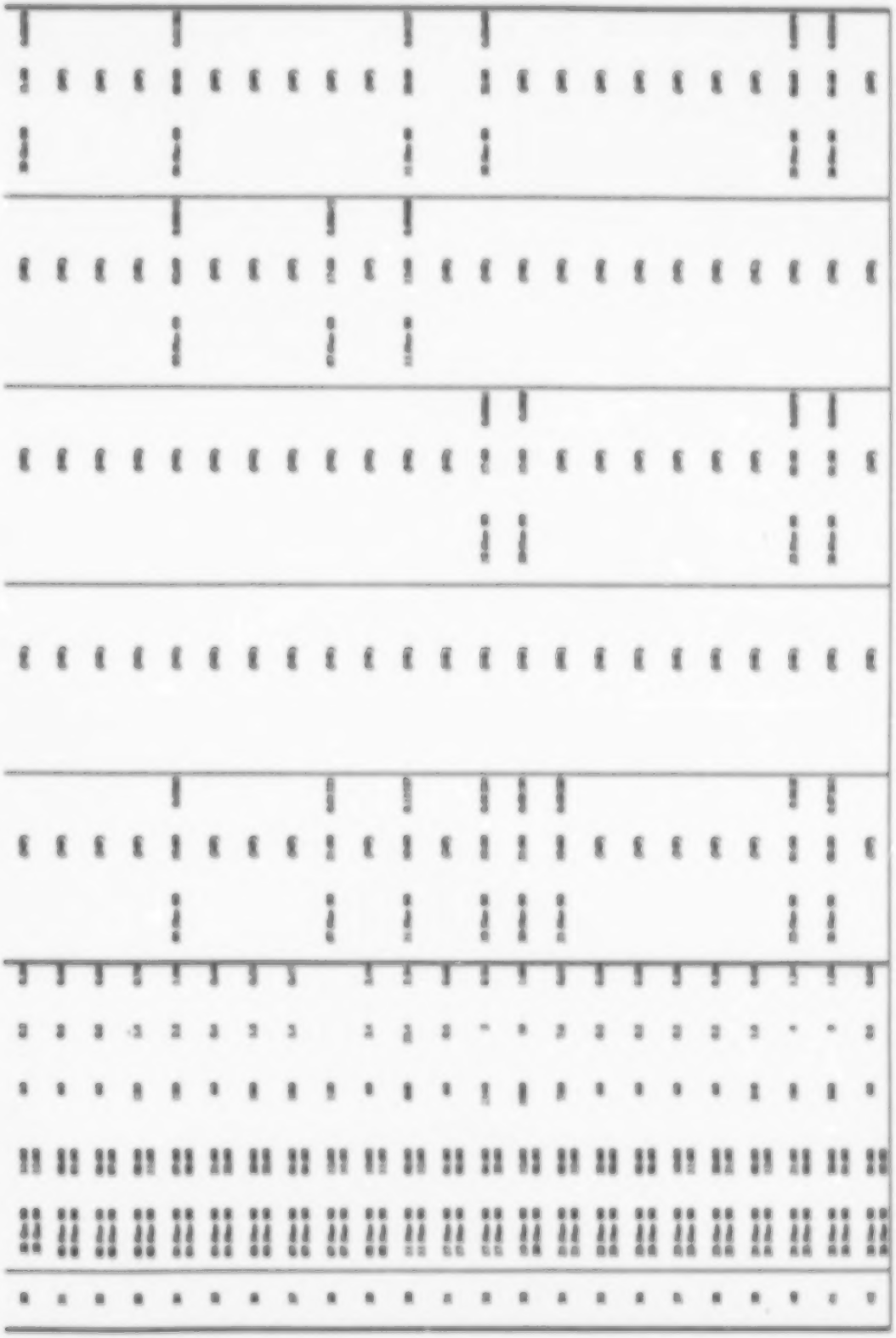
APPENDIX A PRECIPITATION AND SELECTED STREAM FLOW DATA

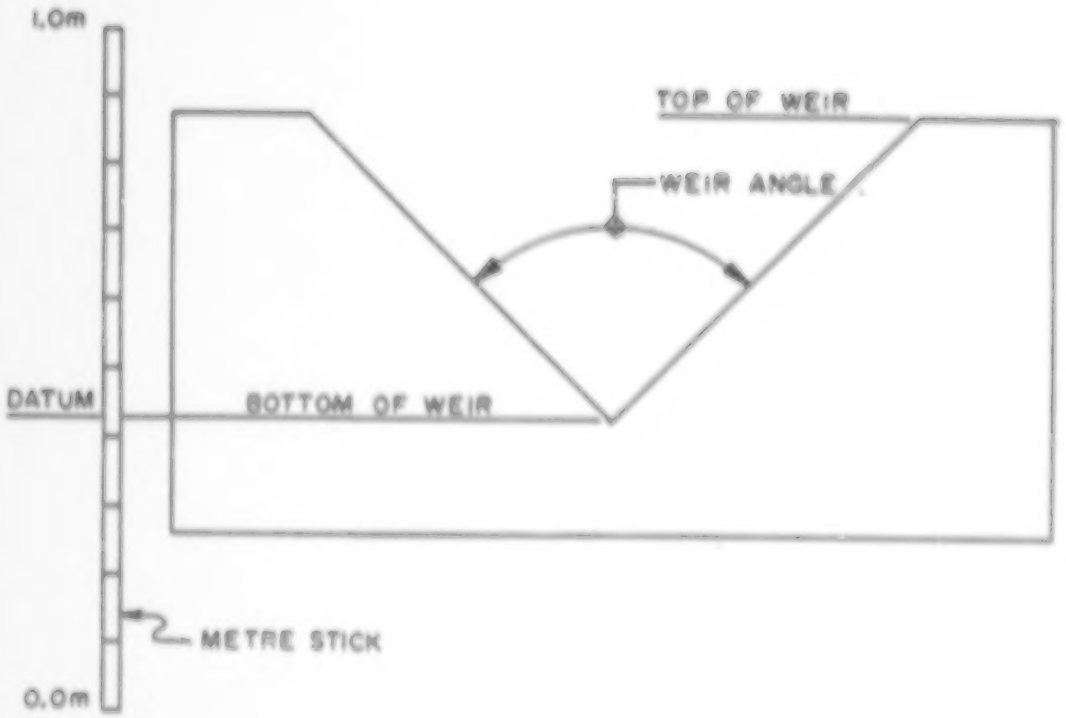
TABLE A-3 MEAN MONTHLY PRECIPITATION - BATHURST, N.B.

MONTH	RAINFALL	SNOWFALL MM	TOTAL PRECIPITATION MM
January	19.1	63.3	82.4
February	18.4	54.5	72.9
March	21.0	57.8	78.8
April	41.9	23.4	65.3
May	72.6	2.8	75.4
June	72.4	-	72.4
July	83.3	-	83.3
August	88.3	-	88.3
September	75.6	-	75.6
October	79.1	2.2	81.3
November	64.7	22.3	87.0
December	27.4	55.8	83.2
TOTALS	663.8	282.1	945.9





APPENDIX B WEIR AND PIEZOMETER DETAILS



WEIR NO.	WEIR ANGLE	TOP OF WEIR ELEV. m	BOT. OF WEIR ELEV. m	DATUM
1	60°	10.458'	10.000'	0.276 m
2	90°	4.637	4.180	0.077 m
3	90°	4.347	3.890	0.082 m
4	30°	8.737	8.280	0.604 m
5	30°	7.632	7.175	0.085 m
6	60°	5.328	4.871	0.170 m
7	90°	5.314	4.857	0.309 m

' Assumed elevation

PIEZOMETER	TOP OF PIPE ELEVATION	STICK UP	GROUND ELEVATION	TOP OF SCREEN ELEVATION	BOTTOM OF SCREEN ELEVATION
P1	11.020	0.914	10.106	10.106	7.566
P2	10.247	1.247	9.000***	9.000	7.000
P3	10.441	1.000	9.441***	9.441	6.314
P3d	10.684	1.243	9.441***	5.800	3.000
P4	10.770	0.914/ 0.490	9.856	10.106	7.900
P5	10.013	1.013	9.000***	9.000	7.000
P6	6.869	1.067	5.802	5.739	4.558
P6a	5.199*		4.500		
P7	6.604	0.864	5.740	5.740	4.734
P8	5.825	1.143	4.682	4.682	3.258
P9	5.744	0.918	4.826	4.753	3.204
P9d	6.126	1.300	4.826	3.000	1.000
P10	5.228	1.016	4.212	4.212	2.789
P11	5.000	1.070	3.930	3.930	1.923
P12	9.591	0.150	9.441***	6.924	6.314
P13	9.591	0.150	9.441***	9.441	8.523
PL	7.437**				

* Meter stick ** Meter stick in lake *** Assumed

APPENDIX C INSTRUMENTATION

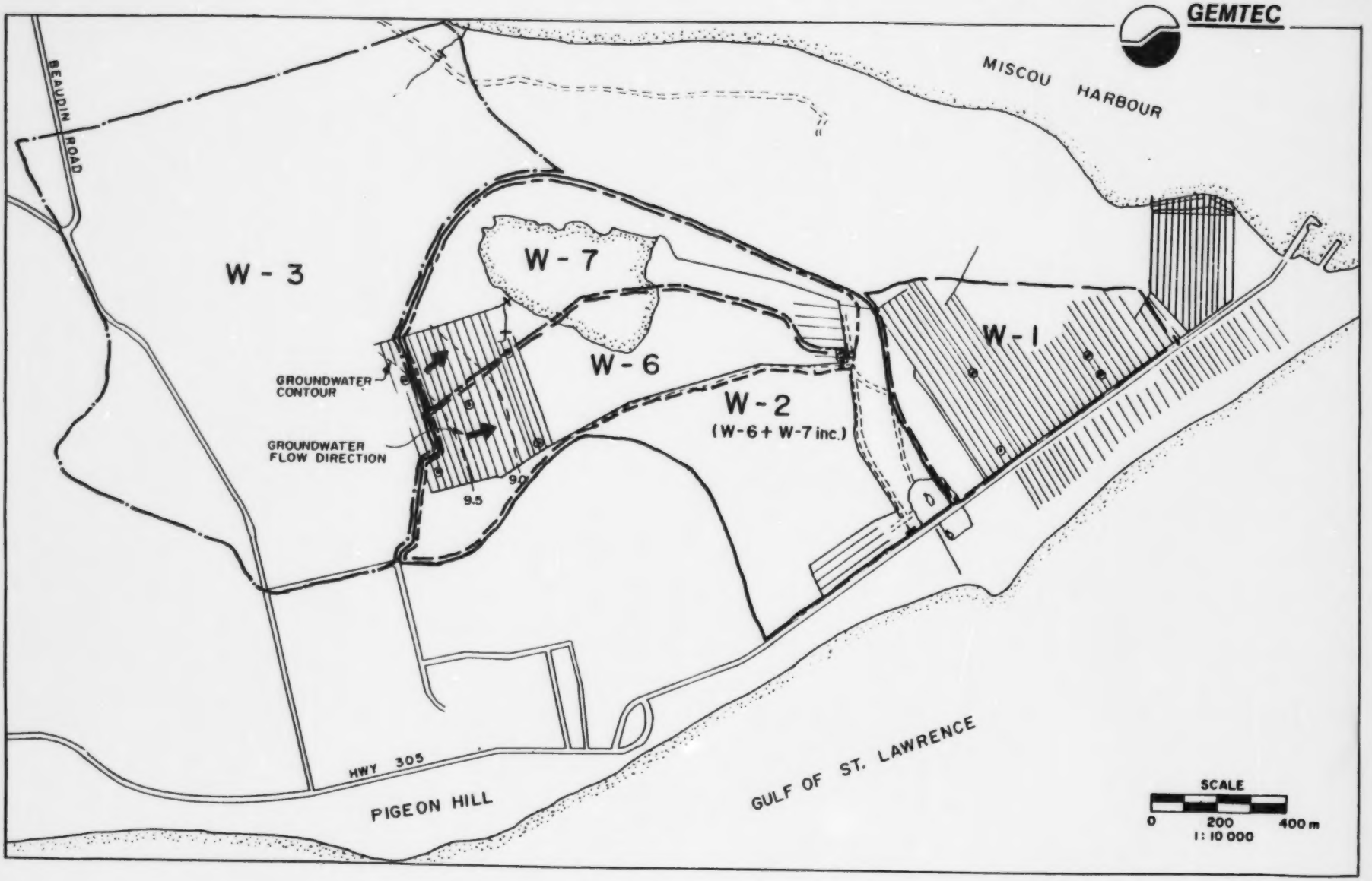
INSTRUMENTATION

Several SINCO VWP PIN 5261-3000 vibrating wire pressure transducers and compatible data collectors were installed at weir and piezometer locations throughout the study area. The SINCO instrumentation provided continuous water-level measurements at the piezometer locations and flow measurements at the weirs. Stations W-2, W-3, W-4, W-6, W-7, P-3 and P-3d were monitored by means of the data loggers during the study period; W-2 and W-7 continuously, and the others at intermittent periods. Water levels at W-1 and W-5, as well as at the remaining 13 piezometers, were read manually. Periodically, the data were downloaded in the field with the data-recorder software (DCM) to dBASE III, using an Olivetti M 111 portable computer. Eventually all data were transferred to a LOTUS 1 2 3 spreadsheet.

An automated tipping-bucket rain gauge was installed at a location in Pigeon Hill (1 km from the site), to provide a continuous precipitation record over the course of the study period. Rainfall information was collected on a revolving drum chart recorder. Data were then transferred manually to a LOTUS 1 2 3 spreadsheet.

Horizontal and vertical control for each weir and piezometer were determined using a TOPCON GB-3C Geodetic Total Station.

APPENDIX D MAP OF CATCHMENT AREAS


GEMTEC
MISCOU HARBOUR
BEAUDIN ROAD
W - 3
W - 7
W - 6
W - 1
W - 2
(W-6 + W-7 inc.)
GROUNDWATER CONTOUR
GROUNDWATER FLOW DIRECTION
9.5
9.0
HWY 305
PIGEON HILL
GULF OF ST. LAWRENCE
SCALE
0
200
400 m
1: 10 000

APPENDIX E LOGS OF BOREHOLES AND SECTION THROUGH SOUTH FIELD

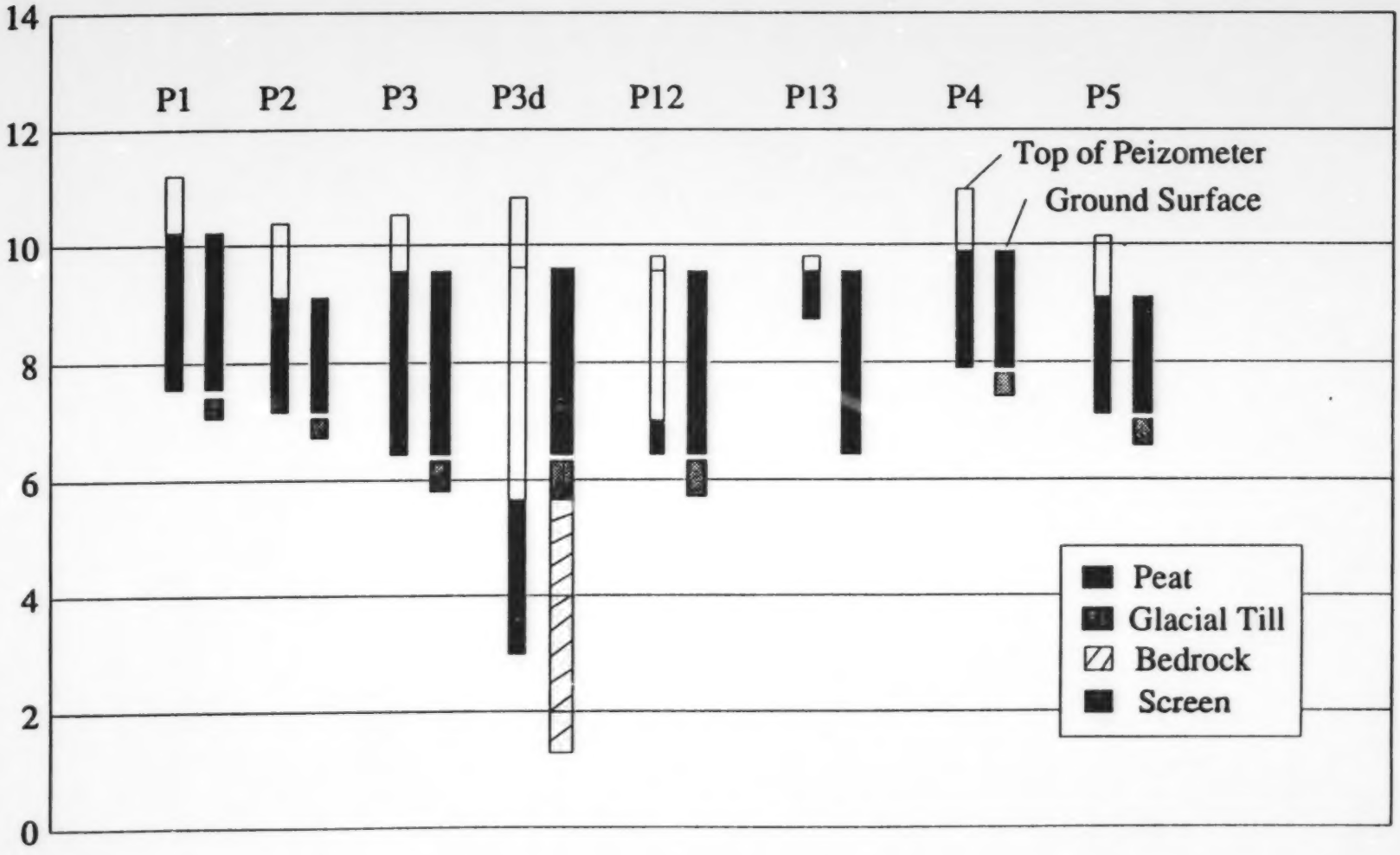
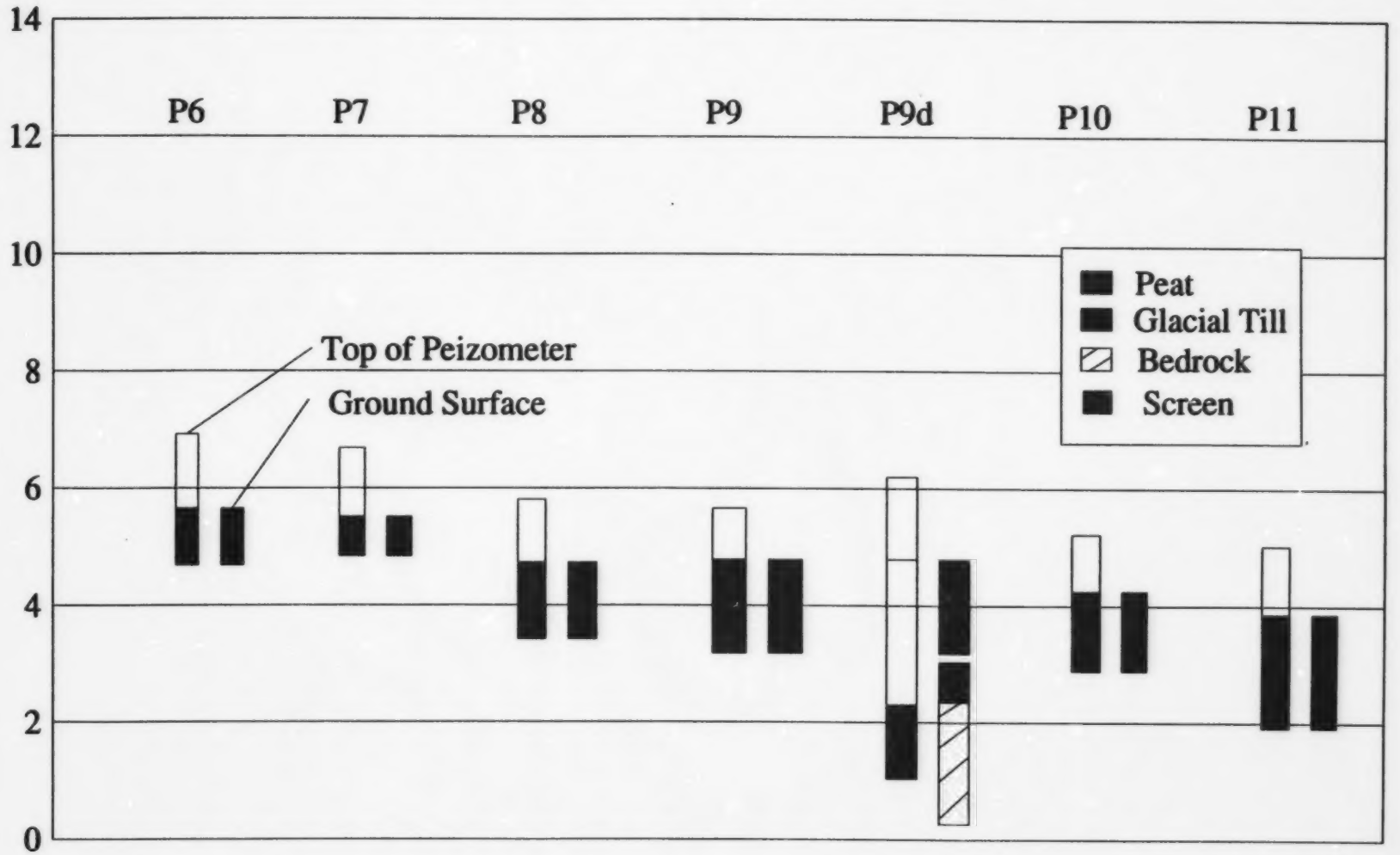


FIGURE 1 BOREHOLE LOGS


14
12
10
8
6
4
2
0
P6
P7
P8
P9
P9d
P10
P11
Top of Peizometer
Ground Surface
Peat
Glacial Till
Bedrock
Screen

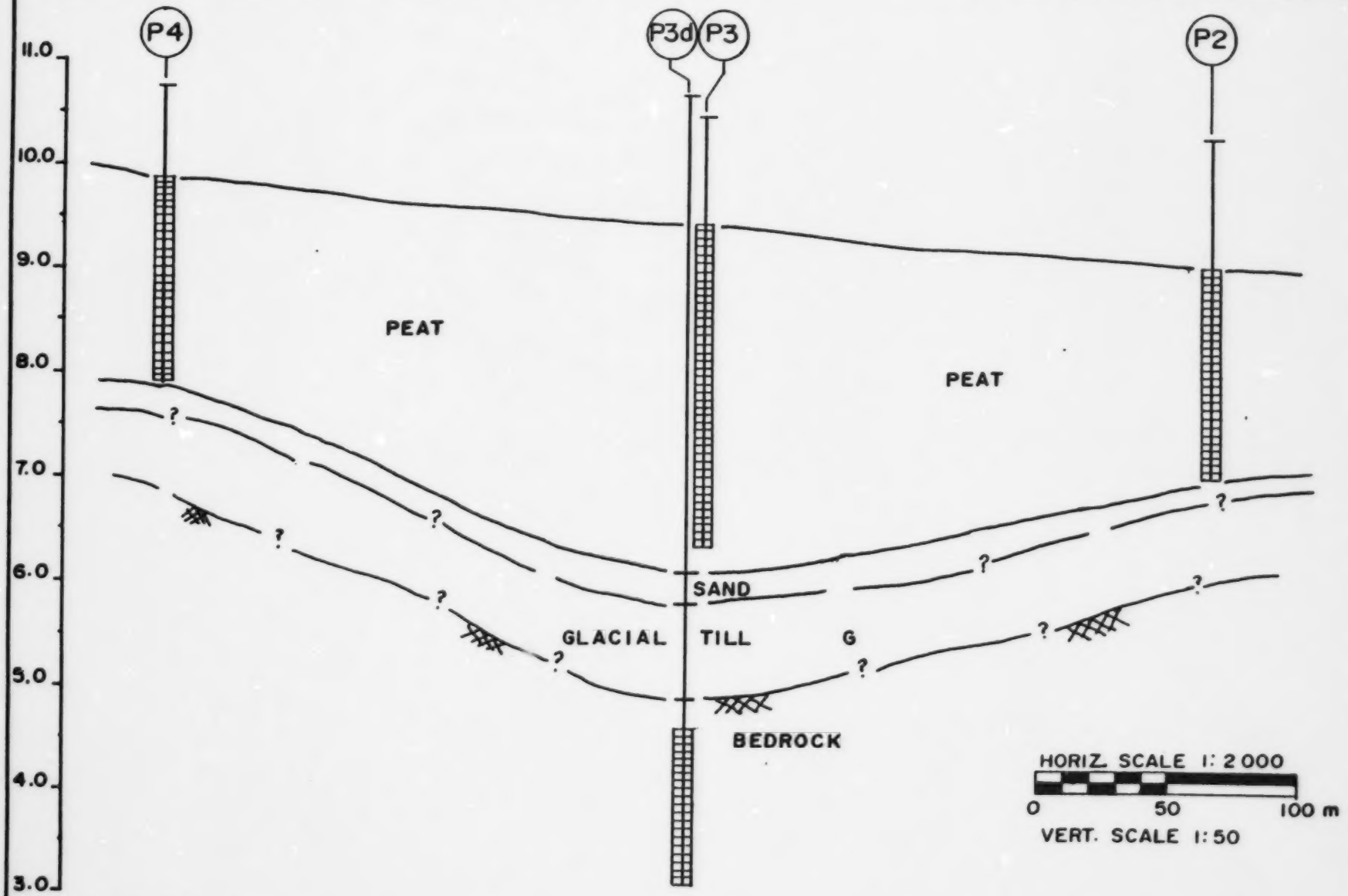


FIGURE 2 SECTION THROUGH SOUTH FIELD

GEMTEC

APPENDIX F ROCK QUALITY DESIGNATION

ROCK QUALITY DESIGNATION

The Rock Quality Designation (RQD) is an indirect measure of the number of fractures and the amount of softening or alterations in a rock mass. It is obtained from the rock cores by summing up the length of core recovered, counting only those pieces of sound core that are 100 mm or more in length. The RQD value is expressed as a percentage and is the ratio of the summed core lengths to the total core length (core run).

Classification of rock with regard to RQD - Value

RQD Classification	RQD - Value %
Very poor quality	<25
Poor quality	25 - 50
Fair quality	50 - 75
Good quality	75 - 90
Excellent quality	90 - 100

Source: Canadian Foundation Engineering Manual

APPENDIX G PROCTOR TEST DESCRIPTION

PROCTOR TEST DESCRIPTION

Compaction is the process of increasing density of a soil by packing the particles closer together with a reduction in the volume of air. The degree of compaction of a soil is measured in terms of dry density, i.e., the mass of solids per unit volume of soil. If the bulk density of the soil is ρ and the water content w, then the dry density is given by:

$$\rho_d = \rho/(1 + w)$$

The compaction characteristics of a soil can be assessed by means of standard laboratory tests. The soil is compacted in a cylinder mould using standard compaction effort (ASTM D698). After compaction the bulk density and water content of the soil are determined and the dry density calculated. For a given soil, the process is repeated several times. Dry density is plotted against water content and a curve is drawn through the points.

At low values of water content most soils tend to be stiff and are difficult to compact. As the water content is increased the soil becomes more workable, facilitating compaction and resulting in higher dry densities. At high water contents, however, the dry density decreases with increasing water content, an increasing proportion of the soil volume being occupied by water.

If all of the air in a soil could be expelled by compaction the soil would be in a state of full saturation and the dry density would be the maximum possible value for a given water content. The maximum possible value of dry density is referred to as the "zero air voids" dry density and can be calculated from the following equation:

$$\rho_d = \left(G_s/1+wG_s \right) \rho_w$$

Source: Craig, 1984.

Designation: D 698 – 78[ε1]

An American National Standard

Standard Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 5.5-lb (2.49-kg) Rammer and 12-in. (305-mm) Drop[1]

This standard is issued under the fixed designation D 698; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

These methods have been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

[ε1] NOTE—The title was corrected editorially in July 1988.

1. Scope

1.1 These laboratory compaction methods cover the determination of the relationship between the moisture content and density of soils and soil-aggregate mixtures (Note 1) when compacted in a mold of a given size with a 5.5-lb (2.49-kg) rammer dropped from a height of 12 in. (305 mm) (Note 2). Four alternative procedures are provided as follows:

1.1.1 *Method A*—A 4-in. (101.6-mm) mold; material passing a No. 4 (4.75-mm) sieve;

1.1.2 *Method B*—A 6-in. (152.4-mm) mold; material passing a No. 4 (4.75-mm) sieve;

1.1.3 *Method C*—A 6-in. (152.4-mm) mold; material passing a ¾-in. (19.0-mm) sieve; and

1.1.4 *Method D*—A 6-in. (152.4-mm) mold; material passing a ¾-in. (19.0-mm) sieve, corrected by replacement for material retained on a ¾-in. sieve.

NOTE 1—Soils and soil-aggregate mixtures should be regarded as natural occurring fine- or coarse-grained soils or composites or mixtures of natural soils, or mixtures of natural and processed soils or aggregates such as silt, gravel, or crushed rock.

NOTE 2—These laboratory compaction test methods when used on soils and soil-aggregates which are not free-draining will, in most cases, establish a well-defined optimum moisture content and maximum density (see Section 7). However, for free-draining soils and soil-aggregate mixtures, these methods will not, in many cases, produce a well-defined moisture-density relationship and the maximum density obtained will generally be less than that obtained by vibratory methods.

1.2 The method to be used should be indicated in the specifications for the material being tested. If no method is specified, the provisions of Section 5 shall govern.

2. Referenced Documents

2.1 *ASTM Standards:*

C 127 Test Method for Specific Gravity and Absorption of Coarse Aggregate[2]

D 854 Test Method for Specific Gravity of Soils[3]

D 2168 Methods for Calibration of Laboratory Mechanical-Rammer Soil Compactors[3]

D 2216 Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures[3]

D 2487 Test Method for Classification of Soils for Engineering Purposes[3]

D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)[3]

E 11 Specification for Wire-Cloth Sieves for Testing Purposes[4]

3. Apparatus

3.1 *Molds*—The molds shall be cylindrical in shape, made of rigid metal and be within the capacity and dimensions indicated in 3.1.1 or 3.1.2. The molds may be the "split" type, consisting either of two half-round sections, or a section of pipe split along one element, which can be securely locked together to form a cylinder meeting the requirements of this section. The molds may also be the "taper" type, providing the internal diameter taper is uniform and is not more than 0.200 in./linear ft (16.7 mm/linear m) of mold height. Each mold shall have a base plate assembly and an extension collar assembly, both made of rigid metal and constructed so they can be securely attached to or detached from the mold. The extension collar assembly shall have a height extending above the top of the mold of at least 2 in. (50.8 mm), which may include an upper section that flares out to form a funnel provided there is at least a ¾-in. (19-mm) straight cylindrical section beneath it.

3.1.1 *Mold*, 4.0 in. (101.6 mm) in diameter, having a capacity of $^1/_{30} \pm 0.0004$ ft^3 (944 ± 11 cm^3) and conforming to Fig. 1.

3.1.2 *Mold*, 6.0 in. (152.4 mm) in diameter, having a capacity of $^1/_{13.333} \pm 0.0009$ ft^3 (2124 ± 25 cm^3) and conforming to Fig. 2.

3.1.3 The average internal diameter, height, and volume of each mold shall be determined before initial use and at intervals not exceeding 1000 times the mold is filled. The

[1] These test methods are under the jurisdiction of ASTM Committee D-18 on Soil and Rock and are the direct responsibility of Subcommittee D18.03 on Texture, Plasticity and Density Characteristics of Soils.

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[2] *Annual Book of ASTM Standards*, Vols 04.02 and 04.03.

[3] *Annual Book of ASTM Standards*, Vol 04.08.

[4] *Annual Book of ASTM Standards*, Vols 04.01, 04.06, and 14.02.

mold volume shall be calculated from the average of at least six internal diameter and three height measurements made to the nearest 0.001 in. (0.02 mm), or from the amount of water required to completely fill the mold, corrected for temperature variance in accordance with Table 1. If the average internal diameter and volume are not within the tolerances shown in Figs. 1 or 2, the mold shall not be used. The determined volume shall be used in computing the required densities.

3.2 *Rammer*—The rammer may be either manually operated (see 3.2.1) or mechanically operated (see 3.2.2). The rammer shall fall freely through a distance of 12.0 ± 1/16 in. (304.8 ± 1.6 mm) from the surface of the specimen. The manufactured weight of the rammer shall be 5.5 ± 0.02 lb (2.49 ± 0.01 kg). The specimen contact face shall be flat.

3.2.1 *Manual Rammer*—The specimen contact face shall be circular with a diameter of 2.000 ± 0.005 in. (50.80 ± 0.13 mm). The rammer shall be equipped with a guidesleeve which shall provide sufficient clearance so that the free fall of the rammer shaft and head will not be restricted. The guidesleeve shall have four vent holes at each end (eight holes total) located with centers 3/4 ± 1/16 in. (19.0 ± 1.6 mm) from each end and spaced 90 deg apart. The minimum diameter of the vent holes shall be 3/8 in. (9.5 mm).

TABLE 1 Volume of Water per Gram based on Temperature[A]

Temperature, °C (°F)	Volume of Water, ml/g
12 (53.6)	1.00048
14 (57.2)	1.00073
16 (60.8)	1.00103
18 (64.4)	1.00138
20 (68.0)	1.00177
22 (71.6)	1.00221
24 (75.2)	1.00268
26 (78.8)	1.00320
28 (82.4)	1.00375
30 (86.0)	1.00435
32 (89.6)	1.00497

[A] Values other than shown may be obtained by referring to the *Handbook of Chemistry and Physics*, Chemical Rubber Publishing Co., Cleveland, Ohio.

TABLE 2 Dry Preparation Method—Standing Times

Classification D 2487	Minimum Standing Time, h
GW, GP, SW, SP	no requirement
GM, SM	3
ML, CL, OL, GC, SC	18
MH, CH, OH, PT	36

TABLE 3 Precision

	Standard Deviation, s	Acceptable Range of Two Results, Expressed as Percent of Mean Value[A]
Single-operator precision:		
Maximum density	...	1.9
Optimum moisture content	...	9.5
Multilaboratory precision:		
Maximum density	±1.88	4.0
Optimum moisture content	±0.86	15.0

[A] This column indicates a limiting range of values which should not be exceeded by the difference between any two results, expressed as a percentage of the average value. In cooperative test programs it has been determined that 95 % of the tests do not exceed the limiting acceptable ranges shown below. All values shown in this table are based on average test results from a variety of different soils and are subject to future revision.

TABLE 4 Metric Equivalents for Figs. 1 and 2

in.	mm
0.016	0.41
0.026	0.66
1/32	0.80
1/16	1.6
1/8	3.2
1/4	6.4
11/32	8.7
3/8	9.5
1/2	12.7
5/8	15.9
2	50.8
2 1/2	63.5
4	101.6
4 1/4	108.0
4 1/2	114.3
4.584	116.43
6	152.4
6 1/2	165.1
8	203.2
ft³	**cm³**
1/30	944
0.004	11
1/14.286	2124
0.0009	25

3.2.2 *Mechanical Rammer*—The rammer shall operate mechanically in such a manner as to provide uniform and complete coverage of the specimen surface. There shall be 0.10 ± 0.03 in. (2.5 ± 0.8 mm) clearance between the rammer and the inside surface of the mold at its smallest diameter. When used with the 4.0-in. (101.6-mm) mold, the specimen contact face shall be circular with a diameter of 2.000 ± 0.005 in. (50.80 ± 0.13 mm). When used with the 6.0-in. (152.4-mm) mold, the specimen contact face shall have the shape of a section of a circle of a radius equal to 2.90 ± 0.02 in. (73.7 ± 0.5 mm). The sector face rammer shall operate in such a manner that the vertex of the sector is positioned at the center of the specimen. The mechanical rammer shall be calibrated and adjusted, as necessary, in accordance with 3.2.3.

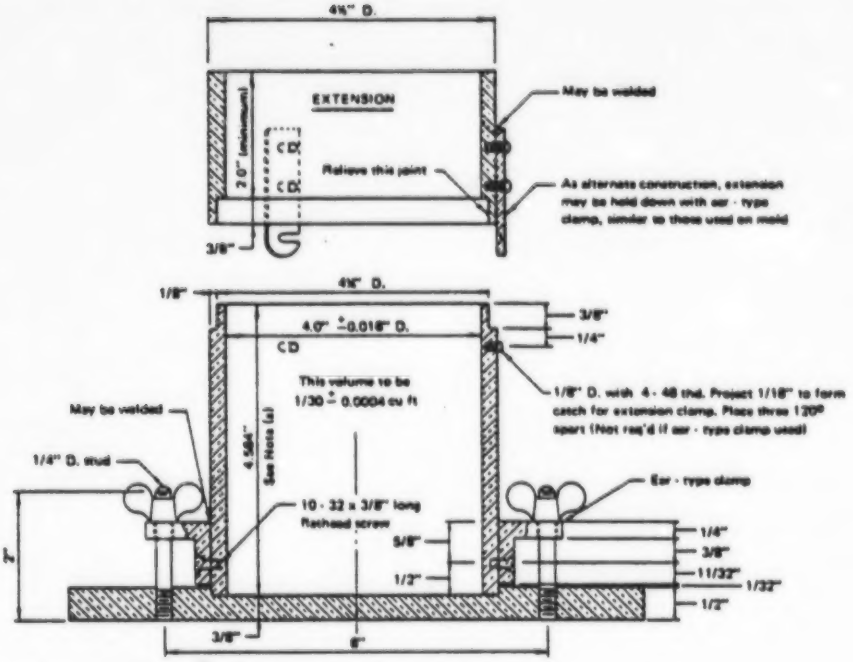
3.2.3 *Calibration and Adjustment*—The mechanical rammer shall be calibrated, and adjusted as necessary, before initial use; near the end of each period during which the mold was filled 1000 times; before reuse after anything, including repairs, which may affect the test results significantly; and whenever the test results are questionable. Each calibration and adjustment shall be in accordance with Methods D 2168.

3.3 *Sample Extruder* (optional)—A jack, frame or other device adapted for the purpose of extruding compacted specimens from the mold.

3.4 *Balances*—A balance or scale of at least 20-kg capacity sensitive to ± 1 g and a balance of at least 1000-g capacity sensitive to ±0.01 g.

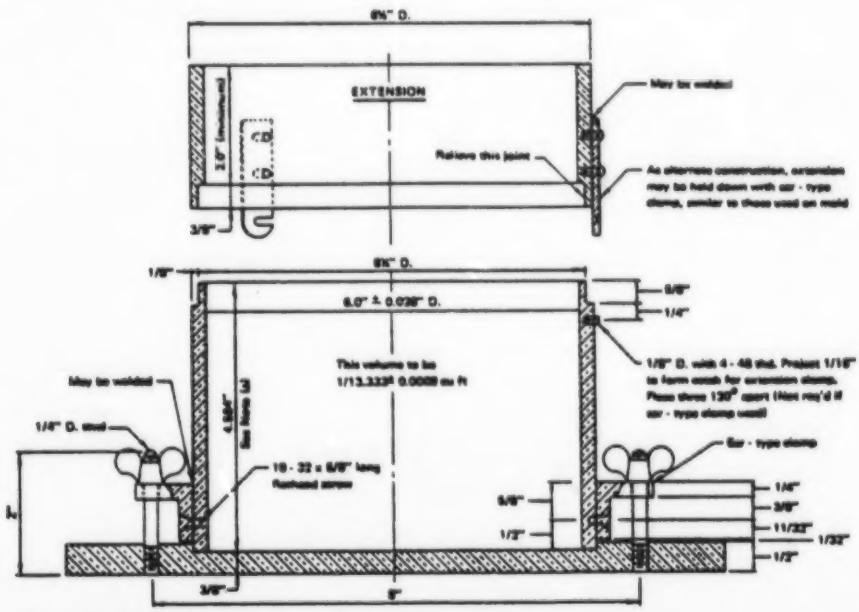
3.5 *Drying Oven*, thermostatically controlled, preferably of the forced-draft type, capable of maintaining a temperature of 230 ± 9°F (110 ± 5°C) for determining the moisture content of the compacted specimen.

3.6 *Straightedge*—A stiff metal straightedge of any convenient length but not less than 10 in. (254 mm). The scraping edge shall have a straightness tolerance of ±0.005 in. (±0.13 mm) and shall be beveled if it is thicker than 1/8 in. (3 mm).



NOTE 1—The tolerance on the height is governed by the allowable volume and diameter tolerances.
NOTE 2—The methods shown for attaching the extension collar to the mold and the mold to the base plate are recommended. However, other methods are acceptable, providing the attachments are equally as rigid as those shown.

FIG. 1 Cylindrical Mold, 4.0-in. for Soil Tests (see Table 4 for metric equivalents)



NOTE 1—The tolerance on the height is governed by the allowable volume and diameter tolerances.
NOTE 2—The methods shown for attaching the extension collar to the mold and the mold to the base plate are recommended. However, other methods are acceptable, providing the attachments are equally as rigid as those shown.

FIG. 2 Cylindrical Mold, 6.0-in. for Soil Tests (see Table 4 for metric equivalents)

3.7 *Sieves*, 3-in. (75-mm), ¾-in. (19.0-mm) and No. 4 (4.75-mm), conforming to the requirements of Specification E 11.

3.8 *Mixing Tools*—Miscellaneous tools such as mixing pan, spoon, trowel, spatula, etc., or a suitable mechanical device for thoroughly mixing the sample of soil with increments of water.

4. Procedure

4.1 *Specimen Preparation*—Select a representative portion of quantity adequate to provide, after sieving, an amount of material weighing as follows: Method A—25 lb (11 kg); Methods B, C, and D—50 lb (23 kg). Prepare specimens in accordance with either 4.1.1 through 4.1.3 or 4.1.4.

4.1.1 *Dry Preparation Procedure*—If the sample is too damp to be friable, reduce the moisture content by drying until the material is friable; see 4.1.2. Drying may be in air or by the use of a drying apparatus such that the temperature of the sample does not exceed 140°F (60°C). After drying (if required), thoroughly break up the aggregations in such a manner as to avoid reducing the natural size of the particles. Pass the material through the specified sieve as follows: Methods A and B—No. 4 (4.75-mm); Methods C and D—¾-in. (19.0-mm). Correct for oversize material in accordance with Section 5, if Method D is specified.

4.1.2 Whenever practicable, soils classified as ML, CL, OL, GC, SC, MH, CH, OH and PT by Test Method D 2487 shall be prepared in accordance with 4.1.4.

4.1.3 Prepare a series of at least four specimens by adding increasing amounts of water to each sample so that the moisture contents vary by approximately 1½ %. The moisture contents selected shall bracket the optimum moisture content, thus providing specimens which, when compacted, will increase in mass to the maximum density and then decrease in density (see 7.2 and 7.3). Thoroughly mix each specimen to ensure even distribution of moisture throughout and then place in a separate covered container and allow to stand prior to compaction in accordance with Table 2. For the purpose of selecting a standing time, it is not required to perform the actual classification procedures described in Test Method D 2487 (except in the case of referee testing), if previous data exist which provide a basis for classifying the sample.

4.1.4 *Moist Preparation Method*—The following alternate procedure is recommended for soils classified as ML, CL, OL, GC, SC, MH, CH, OH, and PT by Test Method D 2487. Without previously drying the sample, pass it through the ¾-in. (19.0-mm) and No. 4 (4.75-mm) sieves. Correct for oversize material in accordance with Section 5, if Method D is specified. Prepare a series of at least four specimens having moisture contents that vary by approximately 1½ %. The moisture contents selected shall bracket the optimum moisture content, thus providing specimens which, when compacted, will increase in mass to the maximum density and then decrease in density (see 7.2 and 7.3). To obtain the appropriate moisture content of each specimen, the addition of a predetermined amount of water (see 4.1.3) or the removal of a predetermined amount of moisture by drying may be necessary. Drying may be in air or by the use of a drying apparatus such that the temperature of the specimen does not exceed 140°F (60°C). The prepared specimens shall then be thoroughly mixed and stand, as specified in 4.1.3 and Table 2, prior to compaction.

NOTE 3—With practice, it is usually possible to visually judge the point of optimum moisture closely enough so that the prepared specimens will bracket the point of optimum moisture content.

4.2 *Specimen Compaction*—Select the proper compaction mold, in accordance with the method being used, and attach the mold extension collar. Compact each specimen in three layers of approximately equal height. Each layer shall receive 25 blows in the case of the 4-in. (101.6-mm) mold; each layer shall receive 56 blows in the case of the 6-in. (152.4-mm) mold. The total amount of material used shall be such that the third compacted layer is slightly above the top of the mold, but not exceeding ¼ in. (6 mm). During compaction the mold shall rest on a uniform rigid foundation, such as provided by a cylinder or cube of concrete weighing not less than 200 lb (91 kg).

4.2.1 In operating the manual rammer, care shall be taken to avoid rebound of the rammer from the top end of the guidesleeve. The guidesleeve shall be held steady and within 5 deg of the vertical. Apply the blows at a uniform rate not exceeding approximately 1.4 s per blow and in such a manner as to provide complete coverage of the specimen surface.

4.2.2 Following compaction, remove the extension collar, carefully trim the compacted specimen even with the top of the mold by means of the straightedge and determine the mass of the specimen. Divide the mass of the compacted specimen and mold, minus the mass of the mold, by the volume of the mold (see 3.1.3). Record the result as the wet density, γ_m, in pounds per cubic foot (or kilograms per cubic metre) of the compacted specimen.

4.2.3 Remove the material from the mold. Determine moisture content in accordance with Method D 2216, using either the whole specimen or alternatively a representative specimen of the whole specimen. The whole specimen must be used when the permeability of the compacted specimen is high enough so that the moisture content is not distributed uniformly throughout. If the whole specimen is used, break it up to facilitate drying. Obtain the representative specimen by slicing the compacted specimen axially through the center and removing 100 to 500 g of material from one of the cut faces.

4.2.4 Repeat 4.2 through 4.2.3 for each specimen prepared.

5. Oversize Corrections

5.1 If 30 % or more of the sample is retained on a ¾-in. (19.0-mm) sieve, then none of the methods described under these methods shall be used for the determination of either maximum density or optimum moisture content.

5.2 *Methods A and B*—The material retained on the No. 4 (4.75-mm) sieve is discarded and no oversize correction is made. However, it is recommended that if the amount of material retained is 7 % or greater, Method C be used instead.

5.3 *Method C*—The material retained on the ¾-in. (19.0-mm) sieve is discarded and no oversize correction is made. However, if the amount of material retained is 10 % or greater, it is recommended that Method D be used instead.

5.4 *Method D:*

5.4.1 This method shall not be used unless the amount of material retained on the ¾-in. (19.0-mm) sieve is 10 % or greater. When the amount of material retained on the ¾-in. sieve is less than 10 %, use Method C.

5.4.2 Pass the material retained on the ¾-in. (19.0-mm) sieve through a 3-in. or 75-mm sieve. Discard the material retained on the 3-in. sieve. The material passing the 3-in. sieve and retained on the ¾-in. sieve shall be replaced with an equal amount of material passing a ¾-in. sieve and retained on a No. 4 (4.75-mm) sieve. The material for replacement shall be taken from an unused portion of the sample.

6. Calculations

6.1 Calculate the moisture content and the dry density of each compacted specimen as follows:

$$w = [(A - B)/(B - C)] \times 100$$

and

$$\gamma_d = [\gamma_m/(w + 100)] \times 100$$

where:

w = moisture content in percent of the compacted specimens,
A = mass of container and moist specimen,
B = mass of container and oven-dried specimen,
C = mass of container,
γ_d = dry density, in pounds per cubic foot (or kilograms per cubic metre) of the compacted specimen, and
γ_m = wet density, in pounds per cubic foot (or kilograms per cubic metre) of the compacted specimen.

7. Moisture-Density Relationship

7.1 From the data obtained in 6.1, plot the dry density values as ordinates with corresponding moisture contents as abscissas. Draw a smooth curve connecting the plotted points. Also draw a curve termed the "curve of complete saturation" or "zero air voids curve" on this plot. This curve represents the relationship between dry density and corresponding moisture contents when the voids are completely filled with water. Values of dry density and corresponding moisture contents for plotting the curve of complete saturation can be computed using the following equation:

$$w_{sat} = [(62.4/\gamma_d) - (1/G_s)] \times 100$$

where:

w_{sat} = moisture content in percent for complete saturation,
γ_d = dry density in pounds per cubic foot (or kilograms per cubic metre),
G_s = specific gravity of the material being tested (see Note 4), and
62.4 = density of water in pounds per cubic foot (or kilograms per cubic metre).

NOTE 4—The specific gravity of the material can either be assumed or based on the weighted average values of: (*a*) the specific gravity of the material passing the No. 4 (4.75-mm) sieve in accordance with Test Method D 854; and (*b*) the apparent specific gravity of the material retained on the No. 4 sieve in accordance with Test Method C 127.

7.2 *Optimum Moisture Content, w_o*—The moisture content corresponding to the peak of the curve drawn as directed in 7.1 shall be termed the "optimum moisture content."

7.3 *Maximum Density, γ_{max}*—The dry density in pounds per cubic foot (or kilograms per cubic metre) of the sample at "optimum moisture content" shall be termed "maximum density."

8. Report

8.1 The report shall include the following.

8.1.1 Method used (Method A, B, C, or D).

8.1.2 Optimum moisture content.

8.1.3 Maximum density.

8.1.4 Description of rammer (whether manual or mechanical).

8.1.5 Description of appearance of material used in test, based on Practice D 2488 (Test Method D 2487 may be used as an alternative).

8.1.6 Origin of material used in test.

8.1.7 Preparation procedure used (moist or dry).

9. Precision

9.1 Criteria for judging the acceptability of the maximum density and optimum moisture content test results are given in Table 3. The standard deviation, s, is calculated from the equation:

$$s^2 = \frac{1}{n-1} \sum_{1}^{n} (x - \bar{x})^2$$

where:

n = number of determinations,
x = individual value of each determination, and
$\bar{x}$ = numerical average of the determinations.

9.2 Criteria for assigning standard deviation values for single-operator precision are not available at the present time.

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